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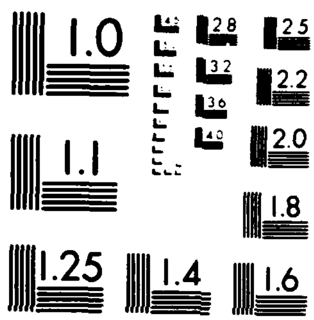

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THESIS

AN EVALUATION OF
ALLOWANCE DETERMINATION
USING OPERATIONAL AVAILABILITY

by

Patrick Joseph O'Reilly

June 1982

Thesis Advisor: F. R. Richards

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marginal analysis techniques and the other model optimizes system availability. The effectiveness of the three different models are compared for four different systems using the NAVSEA TIGER simulation program. The comparisons show that large improvements in system measures of effectiveness can be achieved using the alternative model which optimizes system availability without any increase in total investment costs for allowances. The alternative marginal analysis model did not produce consistently better results over all system configurations than did the FLSIP model.

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An Evaluation of Allowance Determination Using Operational Availability

by

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Submitted in partial fulfillment of the
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ABSTRACT

Shipboard repair part allowances are presently computed using the Fleet Logistics Support Improvement Program which only considers individual part failure rate data and shipboard population. Two alternate allowance determination models are evaluated which consider other logistics factors when computing allowances. One model maximizes repair part availability using marginal analysis techniques and the other model optimizes system availability. The effectiveness of the three different models are compared for four different systems using the NAVSEA TIGER simulation program. The comparisons show that large improvements in system measures of effectiveness can be achieved using the alternative model which optimizes system availability without any increase in total investment costs for allowances. The alternative marginal analysis model did not produce consistently better results over all system configurations than did the FLSIP model.

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I. INTRODUCTION

The United States Navy presently determines repair part allowance quantities for most shipboard applications using procedures established under the Fleet Logistics Support Improvement Program (referred to as the FLSIP model). The FLSIP model was designed before the development of highly sophisticated and powerful third and fourth generation computer hardware and software systems. As a result, in its allowance computations, the FLSIP model considers only individual parts usage data and the total population of each part aboard the ship for which allowances are being computed. FLSIP was also designed to support systems which were much less complex and technologically advanced than those being supported in the Navy of the 1980s and 1990s.

To adjust to changes in technology, improved methods for determining shipboard allowance quantities for repair parts must be developed. To the extent that these improved methods can be supported (by computer technology, data collection procedures, etc.) they should include consideration of as many of the other factors in the logistics environment as possible. This would include system configuration, maintenance policy, operational scenario, supply response times, replacement times, component repair times, spares sharing, and the time horizon mission profile. Due to the escalating costs of repair parts, the increased emphasis on cost efficient management in the military and the likelihood of increasingly restrictive cost constraints on inventory levels in the military, these new allocation methods should attempt to optimize with respect to system availability for any fixed cost in inventory investment.

This paper evaluates two shipboard allowance determination models as alternatives to the FLSIP model. A relatively simple marginal analysis model is evaluated which considers the marginal increase in repair part availability to be gained per dollar spent when determining what repair parts should be allowed. This model requires unit cost data in addition to the data required for the FLSIP model. A much more complex optimization model which focuses on maximizing system availability is also evaluated. In addition to the data required for the FLSIP model, the availability model considers equipment unit cost, equipment Mean Time To Repair (MTTR), total budget constraint, and system configuration data. These models are discussed in detail in Chapter III.

An amended version of the NAVSEA TIGER simulation model is used to compare the effectiveness of each of the three allowance determination models under many different scenarios. Chapter II discusses the capabilities and uses of the amended TIGER simulator. A complete printout of the amended TIGER programs and specific instructions for their use are provided in Appendices B and C. An example of running each allowance determination model on the TIGER simulator is provided in Chapter IV. The results of all the comparisons made during this research are provided in Chapter V.

II. NAVSEA TIGER SIMULATION MODEL

A. INTRODUCTION

The TIGER simulation model is a set of programs developed within NAVSEA to evaluate the performance of complex shipboard operating systems using various measures of effectiveness. This model was modified so that it was compatible with the Naval Postgraduate School computer system in September 1980 by Leather [Ref. 1]. However, due to a complete replacement of hardware and partial replacement of software in December 1980, the model had to be further modified to be compatible with the new computer system. All allowance computations and simulations were run on the IBM system 3033 using the programs in Appendix C. Once data inputs were prepared, an allowance computation and simulation of 1000 missions could be run interactively on a computer terminal in two to six seconds of computer time. All modifications are included in the programs provided in Appendix C.

The TIGER simulation model considers the effect of the following system parameters:

- the Mean Time Between Failures (MTBF) of the equipments/compenents in the system
- the MTTR of the equipments/components in the system
- the interactions between various equipments/components in the system (as reflected in a reliability block diagram of the system)
- the number of spare parts available to support the system
- the operating cycle for the system and the various components of the system

Before running a system, the appropriate data for the above parameters for that system must be input into the TIGER simulator as discussed in Appendix B. Most of the inputs have to be specified exactly, however the TIGER simulator will compute repair part allowances if that is desired. As originally written, the number of repair parts authorized in a system could be specified exactly or a subroutine could be utilized which would compute repair part allowances for the system under FLSIP procedures (which are utilized by the Navy Ships Parts Control Center to actually determine repair part allowances for Navy ships). FLSIP procedures are discussed in detail in Chapter 3, section A. For this research, two additional subroutines were written for the TIGER simulation model so that repair part allowances for a system could also be computed using the Marginal Analysis model discussed in Chapter 3, section B or using the Availability model discussed in Chapter 3, section C. The main program was also modified to accept spare part unit costs and total budget constraints as input parameters for these models.

B. TIGER OPERATION

The TIGER simulator utilizes Monte Carlo random number techniques to estimate part failure times and times to repair based on the assumption that the times between failures for each part are exponentially distributed with parameter MTBF and the repair time for each part is exponentially distributed with parameter MTTR. The operating status of all parts is then observed at all times during the simulation to determine when the system is "up" and when it is "down". The TIGER simulator considers the inter-relationships between the parts (as specified in the reliability block diagram) to determine whether the system is "up" or

"down". When an acceptable combination of parts are operational then the system is considered to be "up". During those periods of time when an acceptable combination of parts are not operational, the system is considered to be "down".

The TIGER simulator measures the effectiveness of a system using the observed "up" and "down" times for that system over a specified number of missions. The length of each mission is included as an input parameter. The number of missions simulated is also specified in the input parameters and must be between 50 and 1000 (in increments of 50). System effectiveness is computed in the following four ways:

1) Estimated reliability is the probability that a system will perform satisfactorily during an entire mission.

$$\text{REL(EST)} = 1 - \frac{\text{Number of Mission Failures}}{\text{Total Number of Simulated Missions}}$$

2) Estimated Instant Availability is the probability that the system will be in an "up" condition at a specific point in time.

$$\text{AVA INSTANT(EST)} = \frac{\text{Number of Missions Up at Time (t)}}{\text{Total Number of Missions Simulated}}$$

This value is calculated at the beginning and end of each phase sequence. A mission can contain up to six different operating scenarios. These are defined as phase sequences. For example, for simulating shipboard operations: one phase can represent in port periods, another can represent normal steaming operations, and a third can represent battle engagement periods. The ability to replace parts and the amount of time a part must be operational for the equipment to be considered in an "up" status can be varied from one

phase type to another. Details for doing this are discussed in Appendix B under Card Types 7, 10 and 13.

3) Estimated Average Availability is the probability that the system will be in an "up" condition at a random point in time.

$$\text{AVA AVERAGE(EST)} = \frac{\text{Summation of Uptime for All Missions Simulated}}{\text{Summation of Total Mission Calender Time for all Missions Simulated}}$$

4) Estimated readiness is the probability that the system will be in an "up" condition at a random point in time assuming that the system stays down for the remainder of each mission after its first failure in that mission.

$$\text{RED(EST)} = \frac{\text{Summation of Uptime for all Missions Simulated (through the first failure)}}{\text{Summation of Total Mission Calender Time for all Missions Simulated}}$$

Estimated instant availability and estimated average availability were used to evaluate the three allowance determination models in this research.

C. PECULIARITIES OF USE IN THIS THESIS

Since the objective of this research was to measure the relative effectiveness of three different repair part allowance determination policies, many of the parameters in the TIGER simulator which could have been varied were not. The following input parameters were held constant throughout this research.

1. Timeline phases. Scenarios can be specified where reliability block diagrams change during different phases of the mission timeframe being simulated. For the purposes of this study, only one phase was used for all simulations which lasted the entire length of each mission.

2. Mean Time To Repair. MTTR was established as one hour for all equipments.

3. Allowable Downtime. Equipments can be allowed to fail for a certain length of time without causing the system to fail regardless of their position in the reliability block diagram by having specified allowable downtimes. The allowable downtimes for all equipments used in this research were set to zero.

4. Three Levels of Repair Parts Support. Additional support from repair parts located at an intermediate level supply activity (ie. a destroyer tender) and at a depot level supply activity (ie. a Naval Supply Center) can be simulated. However, since the objective of this research was to evaluate the effectiveness of shipboard allowances, it was assumed that no support could be obtained from intermediate or depot level activities during the 90 day mission involved.

D. TIGER OUTPUT

The TIGER simulator produces both standard and optional outputs. The various options are discussed in Appendix B under the Printout Option Card. The optional output used for this research was the management summary printout. It first displays most of the user's input, the allowance determination model used to compute repair part allowances (if one was used), and the number of repair parts being used.

The TIGER simulator then prints a message every time the system goes down indicating which components are down and when they will come back up. Since this portion of the output was voluminous and not useful for analysis during this research, it was suppressed.

Next the TIGER simulator prints the cumulative measures of effectiveness for the system after each group of 50 missions has been simulated. Since this portion of the output was voluminous and not useful until all simulations were completed, it was suppressed until the last mission simulation was completed.

The TIGER simulator then produces tables which summarize data about specific equipment failures, the number of repair parts used, and critical equipments.

Examples of the various outputs produced by the TIGER programs are provided in Appendix D. A detailed explanation of these outputs is provided in Reference 4.

III. ALLOWANCE DETERMINATION POLICIES

A. FLEET LOGISTICS SUPPORT IMPROVEMENT PROGRAM (FLSIP) CONCEPT

The FLSIP concept is presently used by the Ship's Parts Control Center (SPCC) to determine repair part allowances for most shipboard applications. It requires two inputs. First, the average usage rate (on an annual basis) must be known for each repair part. This is denoted as the Best Replacement Factor (BRF). Since most initial usage data available to the Navy is in the form of MTBF data, it must be converted for use in the FLSIP model. Since MTBF is measured in hour units and BRF is measured in annual units, the hourly MTBF data must be divided into 8760 (the number of hours in a 365 day year) to get a BRF figure. The formula for conversion is:

$$BRF = \frac{8760}{MTBF}$$

Second, the total number of times each repair part is installed in the various equipments aboard the ship must be known. This is known as the shipboard population (POP). These two numbers are then multiplied to get the expected number of failures for each part aboard that ship in a one year period of time. This is taken as the mean for each part.

$$\text{mean annual demand} = BRF \times POP$$

Ignoring minimum replacement units, technical overrides, etc., the shipboard allowances for each repair part are then determined as follows.

1. If the mean annual demand for a part is greater than or equal to 1.0, the shipboard allowances will be based on anticipated demand. The allowance will be set equal to the minimum number of spares that will provide at least a 90% probability that actual demand for the part during a 90 day period will not exceed the allowance quantity (assuming a Poisson distribution of demand).

2. If the mean annual demand for a repair part is greater than or equal to .25 but less than 1.0, the shipboard allowance will be set to one. These allowances are insurance items. (.25 is the insurance item cut point - also known as the FLSIP cut point.) Several years ago, as a result of funding presures, this cut point was adjusted up from .15 to reduce the number of insurance items allowed. It can be adjusted up or down to provide more or less insurance protection for certain types of ships but the main emphasis in this paper will be with the .25 level.

3. If the mean annual demand for a part is less than .25 (or other specified cut point), no shipboard allowance will be established.

Funding constraints for shipboard repair parts can be accommodated by increasing the FLSIP cut point as discussed above. However, since almost all the parts used in the systems being evaluated for this paper were assumed to be

high failure rate parts, a change of the FLSIP cut point has little effect on the value of parts required to support those systems. This is due to the fact that most of the means were greater than 1.0 so the allowances were based on demand and adequate repair parts were allowed to meet the 90% issue criteria regardless of the insurance item (FLSIP) cut point. Even if the cut point were changed from .25 (ie. one demand every 4 years) to 1.0 (ie. one demand every year), the FLSIP computed allowances would exceed the budget constraints desired in most cases considered in this thesis.

__Note__: A study conducted by the Center For Naval Analysis [Ref. 2] has recommended the following changes to the FLSIP model:

a. Items supporting equipments essential to a primary mission of the ship would be identified and the insurance item stockage threshold for these items would be lowered to .10 (one unit demanded in 10 years), and

b. High demand insurance items would be stocked in insurance quantities of two each instead of one each as is now done.

This revised FLSIP model was not considered in this research.

Since changing the FLSIP cut point was not considered to be an effective way to constrain expenditures for the FLSIP model for the systems analyzed for this paper, the availability objective of the model was varied instead. By varying the availability objective, a budget constraint could effectively be introduced into the FLSIP model. To do

this, the probability of not being out of stock in the FLSIP model was allowed to decrease until a low enough probability was reached to allow a set of FLSIP allowances to be computed within a specified budget constraint. The specified availability started at 90% and was decreased in increments of 5%. At each increment, FLSIP allowances were determined using the decreased probability and the cost of the repair parts was computed. If the total cost of repair parts was less than the funding constraint specified, then that FLSIP repair parts list was used. If the cost exceeded the funding constraint, that repair parts list was discarded and another set of FLSIP allowances were determined using a 5% lower specified availability. This procedure is illustrated on Table I.

Note that some of the different availability levels have the same allowance costs. This is true because they have the same allowance levels. Different availability levels can have the same allowance levels because repair part allowances do not change linearly with availability levels. Since repair parts must change in increments of one, the change in expected availability may decrease substantially by deleting one part. For example, if a part has an MTBF of 1720 hours, the probability of having no demands in a 90 day period is 28%. So protection levels between zero and 28% can be obtained without carrying any spares. If, on the other hand, one spare is carried, a protection level of 64% is obtained. So protection levels between 29% and 64% all require that one spare be carried. For the program written for this research, that means that protection levels of 60%, 55%, 50%, 45%, 40%, 35% and 30% would all require an allowance of one. Not until the required availability level reached 25% would there be a change in the allowance for this part.

TABLE I

Use of the Availability Objective in the .25 FLSIP Model

The availability objective is varied in the .25 FLSIP model to facilitate the computation of allowances within specified budget constraints. The use of the availability objective for this purpose is demonstrated with the following system.

Part Number	MTBF	POP	MEAN ANNUAL DEMAND	Unit Cost
1	25000	1	.34	150.00
2	1500	1	5.84	151.00
3	750	1	11.68	152.00
4	750	1	11.68	153.00
5	1500	1	5.84	154.00
6	7500	1	1.17	155.00
7	7500	1	1.17	156.00
8	2500	1	3.40	157.00

For this system, unconstrained .25 FLSIP allowances would cost $3058.00 as shown on the 90% availability line below. To determine the allowances when the funding is constrained to 75% of the fully funded costs (ie. 2293.50), the amended TIGER FLSIP procedure is:

1st: Set the high limit for the constrained allowances to 5% higher than the specified limit (the high limit here is $2293.50 X 1.05 = $2408.18). This is done to ensure that optimal combinations just just slightly above the specified budget constraint will be considered.

2nd: Compute spares required for various availability objectives (starting at 90% and going down 5% at a time) until a set of spares is found which will be less than the budget limit high as shown below.

% AVAIL OBJECT	COST	Number of Repair Parts Part #1	Part #2	Part #3	Part #4	Part #5	Part #6	Part #7	Part #8
90	$3058	1	3	5	5	3	1	1	1
85	3058	1	3	5	5	3	1	1	1
80	2448	1	2	4	4	2	1	1	1
75	2448	1	2	4	4	2	1	1	1
70	2448	1	2	4	4	2	1	1	1
65	2143	1	2	3	3	2	1	1	1

Since $2143 is less than $2408, the repair parts computed at the 65% availability objective will be used as the allowances for the 75% funding level.

B. MARGINAL ANALYSIS CONCEPT

One of the deficiencies of the FLSIP model as now used is that it ignores the cost of the spare parts in its computations and in the decision process. The FLSIP model is also very limited in its ability to adjust to funding constraints because this is presently only done by adjusting the insurance cut point. This can result in the inefficient allocation of budget dollars due to variances in the relationships between the unit costs and the reliabilities of the various repair parts. The marginal analysis concept, on the other hand, does consider the cost of the individual items and is designed to accomodate a budget constraint on the total amount of dollars available for spare parts. There are many different possible marginal analysis policies. The one evaluated in this paper selects that combination of parts (for a given set of parts) that will provide the highest total parts availability for a given dollar value constraint. Four inputs are required for this concept. The following three inputs must be known for each part: MTBF, total number of parts in the system, and the unit cost. In addition, a total dollar value constraint for the repair parts allowance must be known. The shipboard repair part allowances are then determined by stepwise adding an additional spare for that item showing the greatest increase in probability of a fill per dollar spent. The incremental improvement in the probability of a fill is the difference

$$Pi(Xi \leq x) - Pi(Xi \leq x-1) \ ,$$

where x is the number of spares of item i and Xi is the demand for spares of item i. This turns out to be

identically equal to the probability of a demand for exactly x spares or pi(x) = P(Xi=x). The policy is illustrated with a simple example involving only the three parts shown in Figure 3.1.

Part Number	MTBF	Pop	Mean 90 Day Demand	Unit Cost
1	1720	1	1.26	$ 200.00
2	1720	1	1.26	50.00
3	3000	1	.72	100.00

Figure 3.1 Example System for Marginal Analysis Model

Step 1. First, we want to determine the marginal benefit (in probability of filling demands) of adding a single spare of each item. For our example:

p1(1)=.35634142 p2(1)=.35634142 p3(1)=.3518585

Step 2. Then for each part, we determine the marginal benefit to cost ratios by dividing the values in step 1 by the unit cost of the part. For our example:

$$\frac{p1(1)}{C1} = .0017817 \qquad \frac{p2(1)}{C2} = .0071268 \qquad \frac{p3(1)}{C3} = .0035186$$

The resulting value is the marginal benefit per dollar invested of adding one of each of the parts.

Step 3. The part with the highest ratio calculated in step number 2 is assigned a single spare. For our example,

the part with the highest marginal availability is part number 2.

Step 4. The total cost of all assigned repair parts is then compared to the budget constraint. For our example, the current total cost of assigned repair parts is $50.00 as shown in Figure 3.2. If the constraint has been reached or exceeded, the computations are concluded with the parts allowances assigned to that point. If the budget constraint has not been reached, the model continues on to step 5.

Part Number	Allowance	Unit Cost	Total Cost
1	-0-	$200.00	-0-
2	1	50.00	50.00
3	-0-	100.00	-0-
Total Costs			$50.00

Figure 3.2 Total Costs of Allowances Assigned After First Iteration

Step 5. A revised marginal availability is calculated for the part which was assigned an allowance in step 3. One additional spare is now considered for that part and the probability of that many demands in a 90 day period is calculated. For our example, the revised marginal availability for part number 2 is p2(2) = .22701228. The new marginal benefit to cost rate for this item is then computed by dividing the revised marginal availability of the item by its unit cost. For our example:

$$\frac{p2(2)}{C2} = \frac{.22701228}{50} = .00454024$$

The model then brings along the information from step 2 for those items not selected for an increase in spares in step 3 and repeats the same type of comparison as was done in step 3. For our example, the benefit to cost rates are now:

$$\frac{p1(1)}{C1} = .0017817 \qquad \frac{p2(2)}{C3} = .00454024 \qquad \frac{p3(1)}{C3} = .0035186$$

The next spare will again be assigned to part number 2 since it still shows the maximum rate.

The above process continues until the specified budget constraint is reached.

C. AVAILABILITY CONCEPT

The availability of equipments and systems afloat are a function of many factors as discussed in Chapter 1. One weakness of both the FLSIP and Marginal Analysis models is that neither of them considers many of those factors. They, in essence, ignore many operational issues which should be considered by a model of this type to be as accurate as possible. Another weakness of both of those models is that the measure of effectiveness for the system is not system related and consequently, one cannot relate resources to readiness (ie. system availability). Man Won Jee [Ref. 3: ch. 4], developed a mathmetical model for computing repair part allowances to support any given system. The model optimizes the instant operational availability of a system for any given budgetary constraint. This is referred to as the Availability model. The Availability model improves upon both the FLSIP and Marginal Analysis models by including several more of the pertinent operational factors. Those factors included in the Availability model which are not considered in either of the other models are the Mean

Time To Repair (replace) a component and a consideration of the interactions between the various components in the system. Like the Marginal Analysis model, the Availability model also considers the unit cost of each repair part and the total budget constraint on the repair parts allowed. In addition, the Availability model improves upon the FLSIP and Marginal Analysis models by relating resource utilization to optimizing system availability which is the measure of effectiveness.

For a single component system, Jee showed that the availability after t units of time of a component having n spares is given by

$$A^{(n)}(t) = A^{(n-1)}(t) + ((f * g)^{(n)} * \bar{F})_{(t)}$$

where f(t) is the probability density of component lifetimes, g(t) is the probability density of replacement times, $\bar{F}(t) = P(T \geq t)$ and $(f*g)^{k}$ represents the k-fold convolution of f and g.

Jee further showed that for the special case in which

$f(t) = ((\text{lambda})(e))^{-(\text{lambda})(t)}$;and

$g(t) = ((\text{nu})(e))^{-(\text{nu})(t)}$;

the marginal contribution that the nth spare provides to system availability is:

$$(f^{(k)} * g^{(k)} * \bar{F})_{(t)} =$$

$$\left(\frac{\theta}{\delta}\right)^{k} * \left(\frac{t^{k}}{k!} + \sum_{r=1}^{k} (-1)^{r} * \frac{(k+r-1)^{P}r}{r!\,\delta^{r}} * \frac{t^{(k-r)}}{(k-r)!}\right) e^{-lt}$$

$$+ (-1)^{k+1} * \left(\frac{\theta^{k}}{\delta^{k+1}}\right) * \left(\frac{t^{(k-1)}}{(k-1)!} + \sum_{l=1}^{k-1} \frac{(k+l)^{P}l}{l!\,\delta^{l}} * \frac{t^{(k-l-1)}}{(k-l-1)!}\right) e^{-nt}$$

where: l = lambda, n = nu, 0 = ln, δ = n-l = 0, and

$$n^{P}k = \frac{n!}{(n-k)!} .$$

The above formula is referred to as the JEE formula throughout this paper. All systems analyzed in this paper were assumed to have parts with exponentially distributed times between failures and replacement times so the JEE formula is used for all calculations. An example of the results of using the JEE formula to determine the contribution to system marginal availability of individual spares is shown in Table II. A maximum of 9 spares for a given part are allowed when using the JEE formula in the amended TIGER model written for this research effort.

Jee then developed a repair parts allocation algorithm that utilizes the JEE formula to optimize the instant operational availability of a system by efficiently allocating the number of spares for each component in a "k" component system [Ref. 3: ch. 6]. The algorithm he developed is basically a dynamic program which is then used to determine the most efficient combination of repair parts for each budget amount.

TABLE II

JEE Formula Computations: An Example

Data for Sample System:

Part Number	MTBF	MTTR
1	1000.0	10.00
2	5000.0	10.00
3	3000.0	10.00

Parts 2 and 3 are in parallel. Part 1 is in series with the combination of parts 2 and 3.

The availabilities for each part number for a range from zero to nine repair parts computed by the JEE formula are:

AVAILABILITY MATRIX FOR SPARE 1 IS:

Part No	Allow Qty	Cost	Avail
1	0	0.0	0.115325
1	1	150.00	0.365767
1	2	300.0	0.635161
1	3	450.00	0.826546
1	4	600.0	0.927569
1	5	750.00	0.969831
1	6	900.0	0.984427
1	7	1050.00	0.988708
1	8	1200.0	0.989796
1	9	1350.00	0.990040

AVAILABILITY MATRIX FOR SPARE 2 IS:

2	0	0.0	0.649209
2	1	151.00	0.928926
2	2	302.0	0.988628
2	3	453.00	0.997044
2	4	604.0	0.997925
2	5	755.00	0.997999
2	6	906.0	0.998004
2	7	1057.00	0.998004
2	8	1208.0	0.998004
2	9	1359.00	0.998004

AVAILABILITY MATRIX FOR SPARE 3 IS:

3	0	0.0	0.486752
3	1	152.00	0.836753
3	2	304.0	0.961420
3	3	456.00	0.990750
3	4	608.0	0.995877
3	5	760.00	0.996588
3	6	912.0	0.996669
3	7	1064.00	0.996677
3	8	1216.0	0.996667
3	9	1368.00	0.996667

The sample system shown in Table II will be used to illustrate how the JEE algorithm works. Part numbers 2 and 3 will be used as the first two dynamic programming stages in our illustration. The stage returns from the first two stages are simply the results of initially calculating the marginal contributions of repair parts 2 and 3 using the JEE formula as shown in Table II. These stage returns are then assembled into the matrix shown on Table III so that a sequence of maximum returns from the combination of these two stages can be calculated.

The JEE algorithm always starts in the upper left hand corner of the matrix because that is the minimum cost combination for the two stages being considered. This is the first undominated combination on the matrix. The algorithm determines the cost and system availability of using the combination of repair parts specified at that junction in the matrix. The cost is calculated by simply costing out the repair parts specified at that point. The calculation of the resulting system availability depends upon whether the parts are operating in series or in parallel. If the parts are in series, the system availability is:

$$AVAIL_{sys} = AVAIL_1 * AVAIL_2 \ .$$

If the parts are in parallel, the system availability is:

$$AVAIL_{sys} = 1 - (1 - AVAIL_1) * (1 - AVAIL_2) \ .$$

Parts 2 and 3 shown on Table II are in parallel and the results of the above calculations for the first undominated combination in the matrix on Table III are a cost of $0.0 and an availability of .8199. The same calculations are then made for other pertinent blocks in the matrix. For example, the cost of combining three spares for part number

TABLE III

JEE Algorithm Matrix *

Part Numbers 3 \ 2	0 -0- .6492	1 151 .9289	2 302 .9886	3 453 .9970	4 604 .9979	5 755 .9980	6 906 .9980
0 -0- .4868	-0- .8199	151 .9635	302 .9941	453 .9985	604 .9989	755 .9990	
1 152 .8368	152 .9427	303 .9884	454 .9981	605 .9995	767 .9996	907 .9997	
2 304 .9614	304 .9865	455 .9973	606 .9996	757 .9999	908 .9999	1059 .9999	
3 456 .9908	456 .9968	607 .9993	758 .9999	909 .9999	1060 .9999	1211 .9999	
4 608 .9959	608 .9986	759 .9997	910 .9999				
5 760 .9966	760 .9988	911 .9998	1062 .9999				
6 912 .9967	912 .9988	1063 .9998					
7 1064 .9967	1064 .9988	1215 .9998					

* The top and side rows in the matrix show the number of spares, the total of their unit costs and availability contribution of each of the parts indicated. The numbers within the matrix show the total costs and resulting availabilities from combining the numbers of spares indicated.

2 with three spares for part number three is $909 and the resulting availability for this same combination is .9999. The calculations do not have to be made for all combinations as discussed in detail by Jee [Ref. 3: ch. 6].

Next, the JEE algorithm finds that combination in the matrix which has a combined cost less than any other combination with a system availability larger than that of the previous undominated combination. That combination is the next optimal combination in the matrix. This process is repeated until all undominated combinations on the matrix have been identified (a maximum of 99 undominated combinations can be processed using the amended TIGER model written for this research effort). The first 8 undominated combinations are indicated on Table III. The optimal repair parts allocation at any dollar level can be identified by simply following the arrows on the matrix until the specified dollar level is found. For example, on Table III, a combination of three spares for part #2 and zero spares for part #3 would be optimal for budget levels between $453 and $603 while a combination of four spares for part #2 and zero spares for part #3 would be optimal for a budget level of $604.

The undominated combinations from the matrix in Table III are the returns from stage 3. These returns are then combined with the cost and availability data for the part (or combination of parts) in the next stage of the system. In Table IV, the undominated combinations from Table III are combined with the costs and availabilities for part 3 from Table II. As discussed on Table II, these parts are assumed to be in series. The resulting first eight undominated combinations are shown on Table IV. As can be observed from Table IV, a combination of 4 spares for part #1, 1 spare for part #2, and 0 spares for part #3 is optimal for budget levels between $751 and $900, etc.

TABLE IV

JEE Algorithm Matrix *

Part Numbers 2,3 / 1	0,0 -0- .8199	1,0 151 .9635	2,0 302 .9941	3,0 453 .9985	4,0 604 .9989	3,1 605 .9995
0 -0- .1153	-0- .0945	151 .1111	302 .1146	453	604	755
1 150 .3658	150 .2999	301 .3524	452 .3636			
2 300 .6352	300 .5208	452 .6120	602 .6315			
3 450 .8265	450 .6776	601 .7963	752 .8216			
4 600 .9276	600 .7605	751 .8937	902 .9221			
5 750 .9698	750 .7951	901 .9344	1052 .9641			
6 900 .9844	900 .8071	1051 .9485	.9786			
7 1050 .9887	1050 .8106	.9526	.9829			

* The top and side rows in the matrix show the number of spares, the total of their unit costs and and the availability contribution of each of the parts indicated. The numbers within the matrix show the total costs and resulting availabilities from combining the numbers of spares indicated.

This combining of matrices is continued until all the parts in the system are included in one of the two axes of the final matrix. Then the optimal combination of repair parts can be identified for any dollar level by looking at the undominated allocations for that matrix.

IV. EXAMPLE OF EACH ALLOWANCE DETERMINATION MODEL

A. INTRODUCTION

The TIGER programs in Appendix C automatically compute repair part allowances and run simulations using those allowances under the operating scrnarios specified in the input data. The output produced are in three sections:

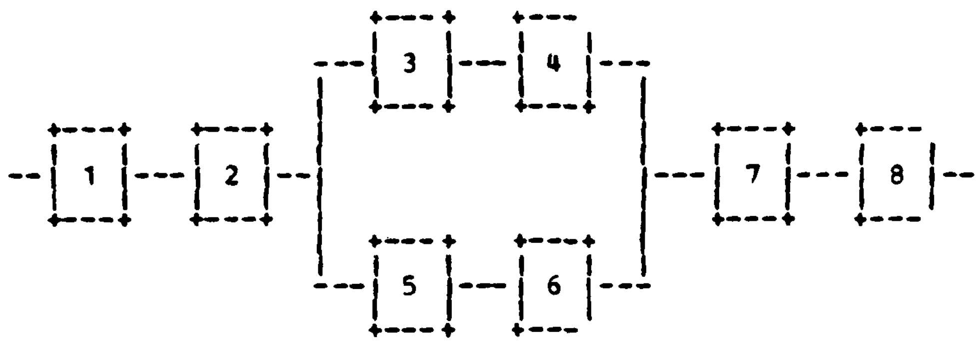
1) the input deck printout;

2) the allowance computation output; and

3) the simulation output.

The input deck printout and simulation output have the same format for all three allowance determination models and are explained in detail in Reference 4, section 4. The allowance computation output was added for this research effort and is different for each of the allowance determination models. The allowance computation outputs are discussed in detail in this chapter. Comparisons between the effectiveness of the three allowance determination models are made in Chapter 5.

The system shown in Figure 4.1 will be used to demonstrate the processing of each allowance determination model. Each of the eight parts are assumed to be unique and have the unit prices and MTBFs shown. The allowances being developed are to sustain operations for 90 days. The format in which the data is input into the programs in Appendix C is discussed in detail in Appendix B.



ITEM NUMBER	MTBF (hours)	UNIT COST
1	25000	150.00
2	1500	151.00
3	750	152.00
4	750	153.00
5	1500	154.00
6	7500	155.00
7	7500	156.00
8	2500	157.00

Figure 4.1 Example System

B. EXAMPLE OF AN UNCONSTRAINED .25 FLSIP MODEL

Table V is the allowance computation output for an unconstrained .25 FLSIP model allowance for the system in Figure 4.1. For an unconstrained FLSIP allowance, the budget specified must be large enough to ensure that all insurance items will have an allowance equal to one and that all demand based items will have an allowance adequate to satisfy 90% of all expected demands during a 90 day period as discussed in Chapter 3, section A.

The first line of output shown is the budget constraint being used. This is shown after the letters "BUDH" which stand for "Budget-High Limit". In our example, the budget

constraint is $10,498.95. This is 5% higher than the actual budget constraint of $10,000 which was input. A 5% flexibility in the budget constraint was selected to ensure that any FLSIP computations that would be just slightly over the constraint specified would still be used for comparison purposes. This was done to ensure the FLSIP model compares as favorably as possible.

TABLE V

FLSIP Example: Allowance Computation Output

```
BUDH 10498.95
SPARES BEING COMPUTED USING FLSIP
XAVAIL = 0.9000
XSUM = 3058.00
SPARES TYPE      SHIP       TENDER      BASE            FACTOR
        1          1            0          0            999.00
        2          3            0          0            999.00
        3          5            0          0            999.00
        4          5            0          0            999.00
        5          3            0          0            999.00
        6          1            0          0            999.00
        7          1            0          0            999.00
        8          1            0          0            999.00
```

The next two lines of output specify that the FLSIP model is being used and what availability probability was used to determine the .25 FLSIP allowances. All computations start at the 90% level (ie-computations produce allowances adequate to provide a 90% probability that the ship will have as many repair parts as demands for repair parts during any given 90 day period of time).

The fourth line of output is the total cost of all allowances required to satisfy the probability level previously specified. This cost is shown after the letters

"XSUM". If XSUM is less than or equal to BUDH, then the repair parts computed during that step will be used as the repair parts for this model. If XSUM is greater than BUDH, then the probability level will be reduced by 5% and another set of repair parts will be computed. In our example, XSUM for the 90% probability level is $3058.00 which is less than the budget limit of $10498.95 so the repair parts computed for this level are used.

The number of spare parts are the last thing shown on this part of the output page. In our example, item numbers (spares type) 1,6,7 and 8 are each assigned one shipboard spare, item numbers 2 and 5 are each assigned three shipboard spares and item numbers 3 and 4 are each assigned five shipboard spares.

For this research, it was assumed that no support could be received from sources other than the shipboard allowances so no spares are assigned to the tender or base levels of supply. The 999.00 in the "FACTOR" column indicates that the allowances shown were determined by the program instead of specified so the 999.00 should be ignored. When spares are specified, the number in this column is a spares multiplier which is explained fully in Appendix B under Card Type 18.

C. EXAMPLE OF A 100% FUNDED MARGINAL ANALYSIS MODEL

When the Marginal Analysis model uses the total costs of an unconstrained .25 FLSIP model allowance as the budget constraint, it is referred to as a 100% funded Marginal Analysis model. For the system in Figure 4.1, the cost of the allowances computed using the unconstrained .25 FLSIP model were $3058.00; so $3058.00 will be used as the budget constraint for the 100% funded marginal analysis model processing for that system.

TABLE VI

Marginal Analysis Example: Allowance Determination Output

```
SPARES WILL BE DETERMINED WITH MARGINAL ANALYSIS
BUDGET IS    3058.
THE COST OF ITEM    1 IS    150.00
THE COST OF ITEM    2 IS    151.00
THE COST OF ITEM    3 IS    152.00
THE COST OF ITEM    4 IS    153.00
THE COST OF ITEM    5 IS    154.00
THE COST OF ITEM    6 IS    155.00
THE COST OF ITEM    7 IS    156.00
THE COST OF ITEM    8 IS    157.00
ALL SPARES HAVE BEEN COMPUTED
```

SPARES TYPE	SHIP	TENDER	BASE	FACTOR
1	0	0	0	999.00
2	3	0	0	999.00
3	5	0	0	999.00
4	4	0	0	999.00
5	3	0	0	999.00
6	1	0	0	999.00
7	1	0	0	999.00
8	2	0	0	999.00

The allowance computation outputs for a Marginal Analysis allowance determination model are different from those for the FLSIP model as shown on Table VI. The first line of output for the Marginal Analysis model is the statement that spares are determined using Marginal Analysis. The budget constraint and unit cost of each item are then printed as well as a statement indicating that all allowances have been computed. The allowance quantities are printed last. For the marginal analysis model, item numbers 6 and 7 are each assigned one spare, item number 8 is assigned two spares, item numbers 2 and 5 are each assigned three spares, item number 4 is assigned four spares, item 3

is assigned five spares and item number 1 is not assigned any spares. Note the differences in the allowances computed using the FLSIP and Marginal Analysis models. The total cost of the allowances determined by the Marginal Analysis model are only $2912.00 compared to $3058.00 for the FLSIP model because the next most cost effective part would have made the total investment in the Marginal Analysis model higher than that of the FLSIP model. Since the system presently in use is the FLSIP system, all unavoidable advantages in comparisons were given to the FLSIP system.

D. EXAMPLE OF A 100% FUNDED AVAILABILITY MODEL

When the Availability model also uses the total costs of an unconstrained .25 FLSIP model allowance as the budget constraint, then the Availability model is referred to as a 100% funded Availability model.

The allowance computation outputs for the Availability allowance determination model are different from the other models as shown on Table VII. The first line of output for the Availability model is the statement that spares were computed using the JEE formula. JTIME and TOTSPR are simply printouts of the input data on the JEE Data card. JTIME equals the number of hours simulated (90 days X 24 hours) and TOTSPR is the maximum number of spares which can be considered for any one repair part; for this example the TOTSPR used was 9. The availability matrix for each spare is then computed. After the availability matrix for the last spare has been printed, the output will indicate that the JEE algorithm has been entered.

Table VII shows the optimal allowances for the 100% funded availability model for the system in Figure 4.1. Item numbers 1,6 and 7 are each assigned two spares, item number 8 is assigned four spares, item numbers 2 and 5 are

TABLE VII

Availability Model: Allowance Determination Output

SPARES BEING COMPUTED USING JEE FORMULA

JTIME IS 2160

TOTSPR IS 9

AVAILABILITY MATRIX FOR SPARE 1 is:

1	0	0.0	0.917227
1	1	150.00	0.996140
1	2	300.0	0.999503
1	3	450.00	0.999598
1	4	600.0	0.999600
1	5	750.00	0.999600
1	6	900.0	0.999600
1	7	1050.00	0.999600
1	8	1200.0	0.999600
1	9	1350.00	0.999600

AVAILABILITY MATRIX FOR SPARE 2 is:

2	0	0.0	0.236928
2	1	151.00	0.578793
2	2	302.0	0.823139
2	3	453.00	0.938486
2	4	604.0	0.978945
2	5	755.00	0.990192
2	6	906.0	0.992774
2	7	1057.00	0.993277
2	8	1208.0	0.993362
2	9	1359.00	0.993375

AVAILABILITY MATRIX FOR SPARE 3 is:

3	0	0.0	0.056135
3	1	152.00	0.219219
3	2	304.0	0.453899
3	3	456.00	0.676929
3	4	608.0	0.834411
3	5	760.00	0.922537
3	6	912.0	0.963249
3	7	1064.00	0.979219
3	8	1216.0	0.984649
3	9	1368.00	0.986275

AVAILABILITY MATRIX FOR SPARE 4 is:

4	0	0.0	0.056135
4	1	153.00	0.219219
4	2	306.0	0.453899
4	3	459.00	0.676929
4	4	612.0	0.834411
4	5	765.00	0.922537
4	6	918.0	0.963249
4	7	1071.00	0.979219
4	8	1224.0	0.984649
4	9	1386.00	0.986275

AVAILABILITY MATRIX FOR SPARE 5 is:

5	0	0.0	0.236928

5	1	154.00	0.578793
5	2	308.0	0.823139
5	3	462.00	0.938486
5	4	616.0	0.978945
5	5	770.00	0.990192
5	6	924.0	0.992774
5	7	1078.00	0.993277
5	8	1232.0	0.993362
5	9	1386.00	0.993375

AVAILABILITY MATRIX FOR SPARE 6 is:

6	0	0.0	0.749762
6	1	155.00	0.964979
6	2	310.0	0.995582
6	3	465.00	0.998456
6	4	620.0	0.998657
6	5	775.00	0.998668
6	6	930.0	0.998668
6	7	1085.00	0.998668
6	8	1240.0	0.998668
6	9	1395.00	0.998668

AVAILABILITY MATRIX FOR SPARE 7 is:

7	0	0.0	0.749762
7	1	156.00	0.964979
7	2	312.0	0.995582
7	3	468.00	0.998456
7	4	624.0	0.998657
7	5	780.00	0.998668
7	6	936.0	0.998668
7	7	1092.00	0.998668
7	8	1248.0	0.998668
7	9	1404.00	0.998668

AVAILABILITY MATRIX FOR SPARE 8 is:

8	0	0.0	0.421473
8	1	157.00	0.785388
8	2	314.0	0.941040
8	3	471.00	0.985012
8	4	628.0	0.994242
8	5	785.00	0.995777
8	6	942.0	0.995988
8	7	1099.00	0.996013
8	8	1256.0	0.996015
8	9	1413.00	0.996015

JEBALG SUBROUTINE HAS BEEN ENTERED

SPARES TYPE	SHIP	TENDER	BASE	FACTOR
1	2	0	0	999.00
2	5	0	0	999.00
3	0	0	0	999.00
4	0	0	0	999.00
5	5	0	0	999.00
6	2	0	0	999.00
7	2	0	0	999.00
8	4	0	0	999.00

each assigned five spares, and item numbers 3 and 4 are not assigned any spares.

If an optimal combination of spares can be determined by the algorithm, the last output will show the quantities of spares computed. However, there are two reasons why the computation of an optimal combination of spares may not be possible. First, the program can handle a maximum of only 9 spares for any given repair part. So, if the optimal solution has any repair parts with more than 9 spares, it cannot be computed. Second, the maximum number of undominated combinations which can be handled by the program is 99 and, if more than 99 undominated combinations are required in any matrix to reach the desired budget constraint, then the optimal solution cannot be computed. If this condition exists, the output will print: "OPTIMAL SOLUTION CANNOT BE COMPUTED". Even though an optimal solution cannot be computed, a set of spare parts will be generated and printed. It should be remembered however that these allowances are not optimal.

E. BUDGET CONSTRAINED EXAMPLES

Any dollar amount can be used as a budget constraint for the three allowance determination models. The FLSIP model will not compute allowances any higher than required to meet its insurance and availability objectives and therefore may not use all funds available. The marginal analysis and availability models will keep assigning spares until the budget constraint is reached.

For this research effort, the performance of the models was observed at budget constraints which were less than necessary to provide fully funded .25 FLSIP allowances. Examples are provided below for the allowance computation outputs for the three models using a budget constraint equal

to 75% of the costs of an unconstrained .25 FLSIP allowance for the system in Figure 4.1. The 75% budget constraint is equal to $2295.00.

The allowance computation outputs for the 75% funded .25 FLSIP model are shown on Table VIII. The program had to compute allowances at six different availability levels before it found one that would produce allowances costing less than the budget constraint (see Chapter 3, section A, for an explanation of this process). At the 90% and 85% availability levels, the allowances computed would cost $3058.00, and at the 80%, 75%, and 70% availability levels, the allowances computed would cost $2448.00. Different availability levels can have the same costs as discussed in detail in Chapter 3, section A. All of these allowance alternatives are more costly than the allowed budget. Not until the computation of the 65% availability level is an allowance combination reached (costing $2143.00) which is less than the budget constraint. The combination of repair parts computed as the 65% allowance level is then used in the TIGER simulation program to compute availabilities.

The allowance computation outputs for the 75% funded Marginal Analysis model are shown on Table IX. The only differences in the output for the 75% funded model and the 100% funded model (Table VI) are the budget constraint used and the allowances specified. The printout for the marginal analysis model does not show the different steps the program is going through to determine the allowances as does the .25 FLSIP model. However, the constrained runs do produce different allowances as can be seen by comparing Tables VI and IX. The 75% funded allowances have one additional spare for item number 1 but have one less spare for item numbers 2, 3, 4, 5 and 8.

TABLE VIII

FLSIP Example(75% funding) : Allowance Determination Output

```
BUDH 2409.75
SPARES BEING COMPUTED USING FLSIP
XAVAIL = 0.9000
XSUM = 3058.00
XAVAIL = 0.8500
XSUM = 3058.00
XAVAIL = 0.8000
XSUM = 2448.00
XAVAIL = 0.7500
XSUM = 2448.00
XAVAIL = 0.7000
XSUM = 2448.00
XAVAIL = 0.6500
XSUM = 2143.00
FLSIP ALLOWS CONSTRAINED BY BUDGET, XAVAIL=.650000
```

SPARES TYPE	SHIP	TENDER	BASE	FACTOR
1	1	0	0	999.00
2	2	0	0	999.00
3	3	0	0	999.00
4	3	0	0	999.00
5	2	0	0	999.00
6	1	0	0	999.00
7	1	0	0	999.00
8	1	0	0	999.00

The allowance computation outputs for the 75% funded Availability model are shown on Table X. The outputs are the same as for the 100% funded Availability model (Table VII) except for the allowances determined. Like the

TABLE IX

75% Funded Marginal Analysis Example: Allowance Determination Output

```
SPARES WILL BE DETERMINED WITH MARGINAL ANALYSIS
BUDGET IS    2295.
THE COST OF ITEM    1 IS    150.00
THE COST OF ITEM    2 IS    151.00
THE COST OF ITEM    3 IS    152.00
THE COST OF ITEM    4 IS    153.00
THE COST OF ITEM    5 IS    154.00
THE COST OF ITEM    6 IS    155.00
THE COST OF ITEM    7 IS    156.00
THE COST OF ITEM    8 IS    157.00
ALL SPARES HAVE BEEN COMPUTED
SPARES TYPE     SHIP      TENDER      BASE          FACTOR
      1           1          0          0           999.00
      2           2          0          0           999.00
      3           4          0          0           999.00
      4           3          0          0           999.00
      5           2          0          0           999.00
      6           1          0          0           999.00
      7           1          0          0           999.00
      8           1          0          0           999.00
```

Marginal Analysis model, the Availability model does not show the different steps the program is going through to determine the allowances.

TABLE X

75% Funded Availability Example: Allowance Determination Output

SPARES BEING COMPUTED USING JEE FORMULA

JTIME IS 2160

TOTSPR IS 9

AVAILABILITY MATRIX FOR SPARE 1 is:

1	0	0.0	0.917227
1	1	150.00	0.996140
1	2	300.0	0.999503
1	3	450.00	0.999598
1	4	600.0	0.999600
1	5	750.00	0.999600
1	6	900.0	0.999600
1	7	1050.00	0.999600
1	8	1200.0	0.999600
1	9	1350.00	0.999600

AVAILABILITY MATRIX FOR SPARE 2 is:

2	0	0.0	0.236928
2	1	151.00	0.578793
2	2	302.0	0.823139
2	3	453.00	0.938486
2	4	604.0	0.978945
2	5	755.00	0.990192
2	6	906.0	0.992774
2	7	1057.00	0.993277
2	8	1208.0	0.993362
2	9	1359.00	0.993375

AVAILABILITY MATRIX FOR SPARE 3 is:

3	0	0.0	0.056135
3	1	152.00	0.219219
3	2	304.0	0.453899
3	3	456.00	0.676929
3	4	608.0	0.834411
3	5	760.00	0.922537
3	6	912.0	0.963249
3	7	1064.00	0.979219
3	8	1216.0	0.984649
3	9	1368.00	0.986275

AVAILABILITY MATRIX FOR SPARE 4 is:

4	0	0.0	0.056135
4	1	153.00	0.219219
4	2	306.0	0.453899
4	3	459.00	0.676929
4	4	612.0	0.834411
4	5	765.00	0.922537
4	6	918.0	0.963249
4	7	1071.00	0.979219
4	8	1224.0	0.984649
4	9	1386.00	0.986275

AVAILABILITY MATRIX FOR SPARE 5 is:

5	0	0.0	0.236928
5	1	154.00	0.578793
5	2	308.0	0.823139
5	3	462.00	0.938486
5	4	616.0	0.978945
5	5	770.00	0.990192
5	6	924.0	0.992774
5	7	1078.00	0.993277
5	8	1232.0	0.993362
5	9	1386.00	0.993375

AVAILABILITY MATRIX FOR SPARE 6 is:

6	0	0.0	0.749762
6	1	155.00	0.964979
6	2	310.0	0.995582
6	3	465.00	0.998456
6	4	620.0	0.998657
6	5	775.00	0.998668
6	6	930.0	0.998668
6	7	1085.00	0.998668
6	8	1240.0	0.998668
6	9	1395.00	0.998668

AVAILABILITY MATRIX FOR SPARE 7 is:

7	0	0.0	0.749762
7	1	156.00	0.964979
7	2	312.0	0.995582
7	3	468.00	0.998456
7	4	624.0	0.998657
7	5	780.00	0.998668
7	6	936.0	0.998668
7	7	1092.00	0.998668
7	8	1248.0	0.998668
7	9	1404.00	0.998668

AVAILABILITY MATRIX FOR SPARE 8 is:

8	0	0.0	0.421473
8	1	157.00	0.785388
8	2	314.0	0.941040
8	3	471.00	0.985012
8	4	628.0	0.994242
8	5	785.00	0.995777
8	6	942.0	0.995988
8	7	1099.00	0.996013
8	8	1256.0	0.996015
8	9	1413.00	0.996015

JEBALG SUBROUTINE HAS BEEN ENTERED

SPARES TYPE	SHIP	TENDER	BASE	FACTOR
1	2	0	0	999.00
2	4	0	0	999.00
3	0	0	0	999.00
4	0	0	0	999.00
5	4	0	0	999.00
6	1	0	0	999.00
7	1	0	0	999.00
8	3	0	0	999.00

V. EVALUATION AND COMPARISON OF THE MODELS

A. SYSTEMS USED FOR EVALUATION

The four systems shown on Figures 5.1 through 5.4 were used to evaluate the three allowance determination models. The systems were selected to illustrate the relative effectiveness of the models in situations where the degree of designed-in system redundancy differs significantly. For example, System A has no designed-in redundancy and will fail whenever any one of the eight components fails whereas System D has a significant degree of designed-in redundancy and will not fail as long as components 1, 8 and 6 or 7 don't fail or components 1, 8 and 2 or 3 and 4 or 5 don't fail.

```
      +---+  +---+  +---+  +---
   ---| 1 |--| 2 |--| 3 |--| 4 |--- A
      +---+  +---+  +---+  +---

      +---+  +---+  +---+  +---
 A ---| 5 |--| 6 |--| 7 |--| 8 |---
      +---+  +---+  +---+  +---
```

Figure 5.1 System A

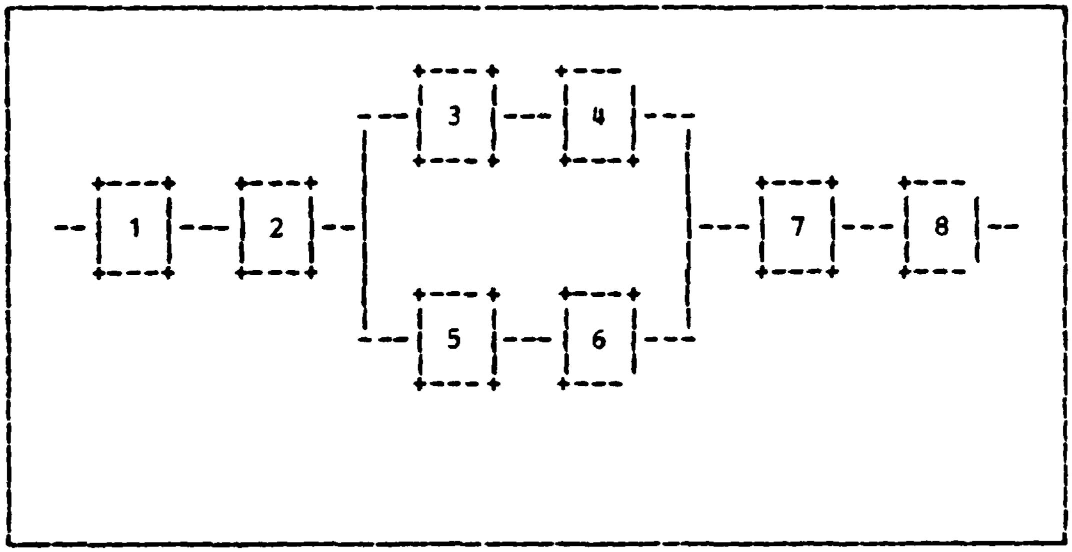


Figure 5.2   System B

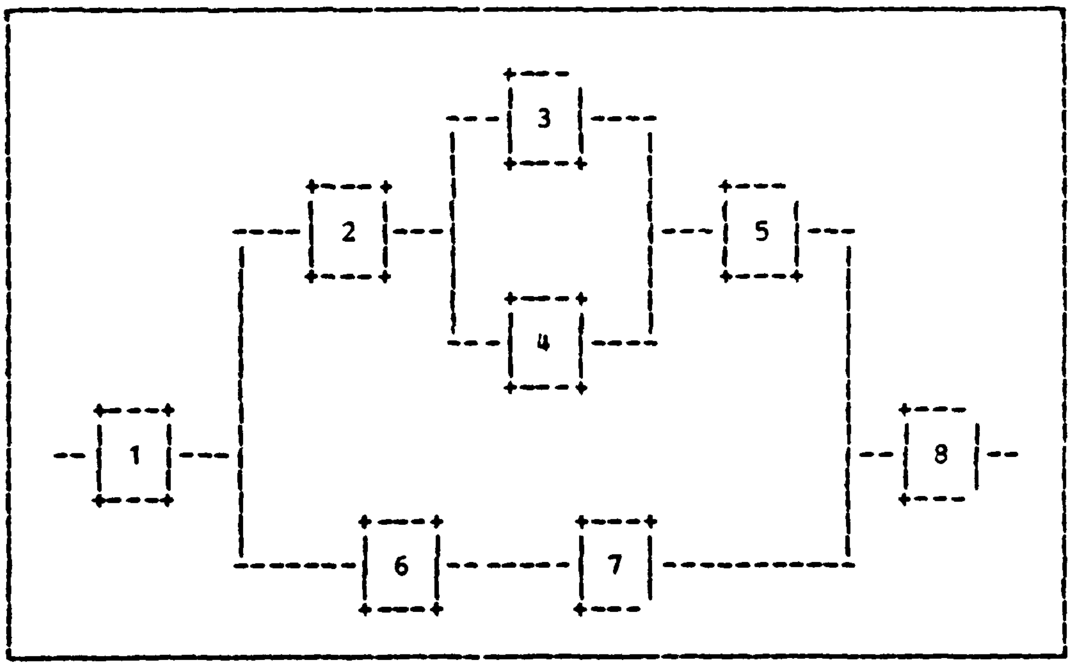


Figure 5.3   System C

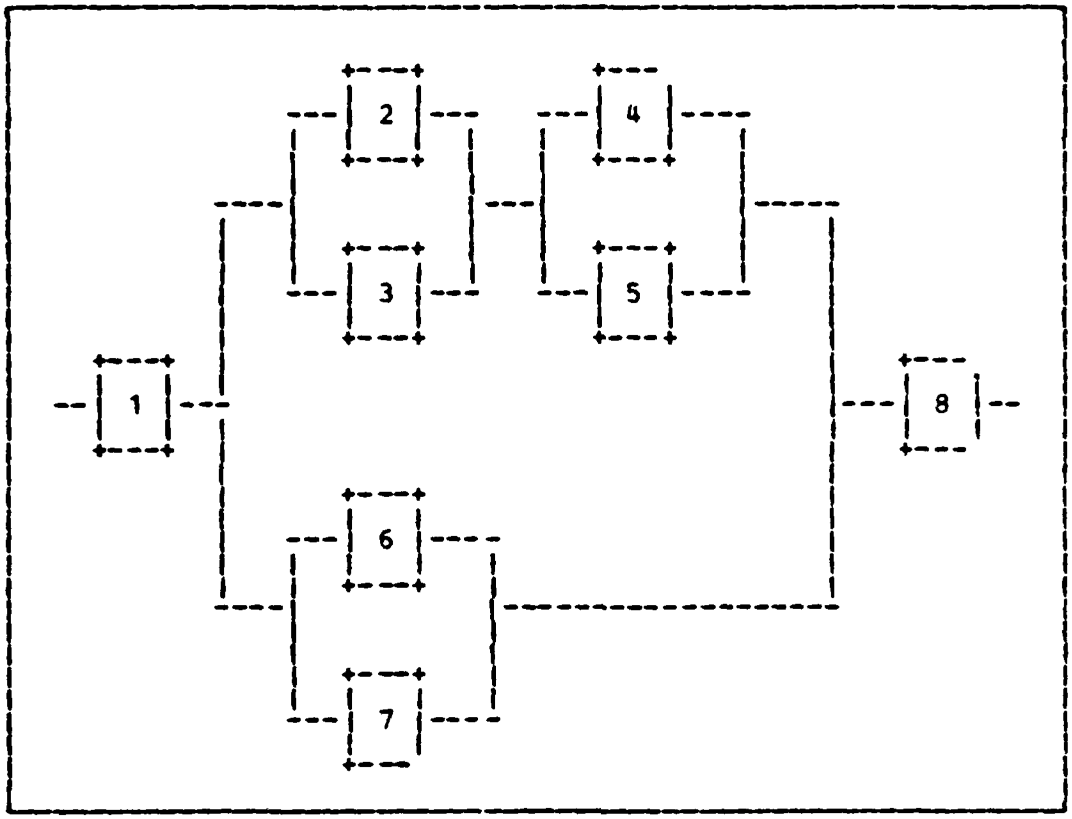


Figure 5.4 System D

B. SCENARIOS USED FOR EVALUATION

The twenty-seven different scenarios shown in Table XI were used in evaluating the three allowance determination models for each of the four systems discussed above.

Since the Marginal Analysis and Availability models explicitly consider component costs and MTBF as part of the allocation algorithm, the three models were compared on systems having a range of variabilities in component unit costs and MTBFs. Any advantages offered by algorithms which consider unit costs should be most apparent for cases in which unit cost variabilities are high. Likewise, any

TABLE XI

Test Scenarios

(Cases are defined in Figures 5.5 and 5.6)

100% Funding *		75% Funding *		50% Funding *	
Part Cost Variance	MTBF Variance	Part Cost Variance	MTBF Variance	Part Cost Variance	MTBF Variance
Case A	Case 1	Case A	Case 1	Case A	Case 1
Case B	Case 1	Case B	Case 1	Case B	Case 1
Case C	Case 1	Case C	Case 1	Case C	Case 1
Case A	Case 2	Case A	Case 2	Case A	Case 2
Case A	Case 3	Case A	Case 3	Case A	Case 3
Case B	Case 2	Case B	Case 2	Case B	Case 2
Case C	Case 2	Case C	Case 2	Case C	Case 2
Case B	Case 3	Case B	Case 3	Case B	Case 3
Case C	Case 3	Case C	Case 3	Case C	Case 3

* based on the budget for the Unconstrained .25 FLSIP allowance list

advantages offered by algorithms which consider the MTBFs of the parts in the system should be most apparent for cases in which MTBF variances are high. So as not to bias the results in favor of any given model, comparisons were also made for cases in which the variability in unit costs and MTBFs were low. The three different sets of part costs shown in Figure 5.5 and the three sets of part MTBF data shown in Figure 5.6 were evaluated.

	Part Number	Case A	Case B	Case C
	1	$150.00	$150.00	$ 50.00
	2	151.00	200.00	400.00
	3	152.00	100.00	500.00
	4	153.00	100.00	500.00
	5	154.00	200.00	400.00
	6	155.00	50.00	50.00
	7	156.00	50.00	50.00
	8	157.00	150.00	50.00
Mean		153.50	125.00	250.00
Standard Deviation		2.45	59.76	217.12

Figure 5.5 Part Cost Sets

Since the Marginal Analysis and Availability models are designed to accomodate funding restrictions and the FLSIP model is not, any advantages offered by the former models should be most apparent for cases in which funding constraints are severe. So as not to bias the results in favor of the alternative models, comparisons were also made for systems where funds were adequate to fully fund FLSIP allowances. Thus, the allowances provided by each model for each combination or scenario of part costs and MTBFs were

Part Number	Case 1	Case 2	Case 3
1	1,720	12,720	25,000
2	1,720	1,000	1,500
3	1,720	2,000	750
4	1,720	4,000	750
5	1,720	3,000	1,500
6	1,720	9,000	7,500
7	1,720	7,720	7,500
8	1,720	18,720	2,500
Mean	1,720	7,270	5,875
Standard Deviation	-0-	6,095	8,222

Figure 5.6 Part MTBF Sets

determined for 100% (unconstrained), 75%, and 50% funding levels. The unconstrained funding level was based on a fully funded .25 FLSIP allowance for each scenario.

The parts required for a .25 FLSIP allowance to support each system under each scenario were determined first. The cumulative cost of those parts was then established as the 100% funding level. This 100% funding figure was then used as a constraint to establish allowances for each scenario using the Marginal Analysis and Availability models. Next, the funding available was constrained to 75% and 50% of the unconstrained FLSIP funding level for each system and scenario. Spares allowances were determined by using each of the three models for a given constrained funding.

C. TEST RESULTS

The results of running the TIGER simulations for the four systems and the 27 scenarios discussed above are shown in Tables XII and XIII. Each system was simulated over 1000

missions (the maximum allowable in the TIGER simulator). A random number seed of 2222 was used for all simulations. The results include both average availability and instant availability.

Of the three allowance determination models, the availability model is the only one which considers system design. The advantages of considering system design when computing repair part allowances are clear in the example used in Chapter 4 (see Figure 4.1). That system is referred to in this chapter as the "B" system. The cost data and MTBF correspond to cases A and 3, respectively. The allowances computed by each allowance determination model for the "B" system are shown in Figure 5.7.

Since the FLSIP system ignores configuration, it assigns the highest number of spares (5 each) to part numbers 3 and 4 since they are expected to fail the most often and are therefore assumed to need the most support. Since the costs of the parts in this system are almost identical, the marginal analysis model essentially assigns spares (in this situation) to those parts which are expected to fail the most since that maximizes the number of demands that will be filled. This procedure results in almost the same allowances as the FLSIP model.

The Availability model recognizes that there is a more reliable parallel leg which can be supported more cost-effectively and therefore assigns no spares to part numbers 3 and 4. This action leaves extra money available to provide additional support to the other non-redundant parts in the system and results in a 10% improvement in system availability over the FLSIP model allowances and an 8% improvement in system availability over the Marginal Analysis model allowances. The availabilities, both average and instantaneous, listed in Tables XII and XIII are 89/91/98.

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TABLE XII

Percent System Availability Achieved

AVERAGE AVAILABILITY

Part Cost Case	MTBF Case	Fund %	(FLSIP/Marginal Analysis/Availability) Sys A	Sys B	Sys C	Sys D
A	1	100	90/90/90	94/94/96	97/97/99	97/97/99
		75	71/71/71	82/82/87	90/90/97	91/91/99
		50	41/41/41	57/57/59	69/69/78	75/75/93
B	1	100	90/89/90	94/95/96	97/aa/99	97/97/99
		75	71/71/72	82/86/87	90/90/98	91/90/99
		50	42/29/36	57/43/50	69/74/90	75/73/95
C	1	100	90/90/ b	94/97/97	97/98/99	97/99/99
		75	71/82/82	82/93/97	89/99/99	91/98/99
		50	42/39/39	57/75/80	69/97/98	75/98/99
A	2	100	83/82/82	95/91/95	99/94/99	99/94/99
		75	68/71/71	83/80/91	99/92/99	99/86/99
		50	a	a	85/80/98	a
A	3	100	83/84/83	89/91/98	91/93/99	92/93/99
		75	67/64/69	84/81/94	89/87/99	91/88/99
		50	47/27/49	70/80/87	89/86/99	91/87/99
B	2	100	83/85/85	95/93/95	99/99/99	99/98/99
		75	68/71/71	83/80/88	98/87/99	99/86/99
		50	a	a	a	a
C	2	100	83/83/85	95/93/98	99/99/99	99/99/99
		75	74/75/75	91/86/96	98/99/99	99/99/99
		50	a	a	a	a
B	3	100	83/82/84	89/87/96	91/94/99	92/93/99
		75	74/77/77	70/69/84	92/92/99	91/94/99
		50	47/43/49	66/63/73	89/87/99	91/87/99
C	3	100	83/88/ b	89/97/ b	91/99/ b	92/99/ b
		75	74/77/ b	85/92/ b	91/99/ b	91/99/ b
		50	47/24/47	70/88/95	85/99/99	91/99/99

	FLSIP	MA	AVA
Total % Greater Than 90% Availability	50	46	65

a - budget constraint was too low to compute a FLSIP allowance
b - optimal combination could not be reached

The overall results of the Marginal Analysis model were somewhat disappointing. For the data collected in Tables XII and XIII, the Marginal Analysis model outperformed the FLSIP model only 37% of the time for average availability (FLSIP did better 43% of the time and they tied 20% of the time) and 31% of the time for instant availability (FLSIP did better 16% of the time and they tied 53% of the time). It also achieved greater than 90% average availability only 46% of the time compared to 50% of the time for FLSIP and 65% of the time for the Availability model. Because of the relatively poor performance of this model compared to the FLSIP model, no further analyses will consider the Marginal Analysis model.

As would be expected, the improvements produced by the Availability model over the FLSIP model are always greater in instant availability than in average availability because the Availability model was designed to optimize instant availability. However, the Availability model also always resulted in the same or higher average availability than did the FLSIP model. Of course, in a given simulation, one might observe that the FLSIP model produces higher availability than does the Availability model just due to chance fluctuation. Indeed this happened for scenarios Case B/Case 1 for 50% funding, Case C/Case 1 for 50% funding, and Case A/Case 2 for 100% funding under System A on Table XII. Subsequent simulation runs using different random number seeds yielded the expected results with the Availability model outperforming the FLSIP model with respect to system availability.

As shown on Table XIV, the level of part cost variance has little influence on availability under the FLSIP model while the level of MTBF variance does significantly affect availability. This is as expected since the FLSIP model

TABLE XIII

Percent System Availability Achieved

INSTANT AVAILABILITY

Part Cost Case	MTBF Case	Fund %	(FLSIP/Marginal Analysis/Availability) Sys A	Sys B	Sys C	Sys D
A	1	100	72/72/72	94/94/96	97/97/99	97/97/99
		75	30/30/30	82/82/93	90/90/97	91/91/99
		50	4/ 4/ 4	57/57/59	69/69/78	75/75/93
B	1	100	72/72/72	94/95/96	97/aa/99	97/97/99
		75	30/32/32	82/86/87	90/90/98	91/90/99
		50	10/10/10	57/43/50	69/74/90	75/73/95
C	1	100	72/74/ b	94/97/97	97/98/99	97/99/99
		75	30/53/52	82/93/97	89/99/99	91/98/99
		50	4/ 6/ 7	57/75/80	69/97/98	75/98/99
A	2	100	58/57/57	95/91/95	99/94/99	99/94/99
		75	30/38/38	83/80/89	99/92/99	99/86/99
		50	a	a	85/80/98	a
A	3	100	55/62/55	89/91/98	91/93/99	92/93/99
		75	23/21/25	84/81/94	89/87/99	91/88/99
		50	4/ 2/ 9	70/80/87	89/86/99	91/87/99
B	2	100	58/60/60	95/93/95	99/99/99	99/98/99
		75	30/38/38	83/80/88	98/86/99	99/87/99
		50	a	a	a	a
C	2	100	58/57/59	95/93/98	99/99/99	99/99/99
		75	39/40/40	91/86/96	98/99/99	99/99/99
		50	a	a	a	a
B	3	100	55/58/62	89/87/96	91/94/99	92/93/99
		75	34/40/40	70/69/84	92/92/99	91/94/99
		50	4/ 6/ 8	66/63/73	89/87/99	91/87/99
C	3	100	55/64/ b	89/97/ b	91/99/ b	92/99/ b
		75	34/36/ b	85/92/ b	91/99/ b	91/99/ b
		50	4/ 1/ 4	70/88/95	85/99/99	91/99/99

	FLSIP	MA	AVA
Total % Greater Than 90% Availability	20	21	52

a - budget constraint was too low to compute a FLSIP allowance
b - optimal combination could not be reached

Allowance Determination Model	Allowances Part Number 1	2	3	4	5	6	7	8
FLSIP	1	3	5	5	3	1	1	1
Marginal Analysis	0	3	5	4	3	1	1	2
Availability	2	5	0	0	5	2	2	4

Figure 5.7 Allowances for Sample System

does explicitly consider MTBF (through the demand rate) but it does not consider part costs.

As shown on Table XIV, the part cost variability has some effect on system availability when the availability model is used. However, the variability in MTBF's has a much more significant effect. Since the systems evaluated in Table XIV are fully funded systems, it appears that in the Availability model the influence of MTBF variance and system configuration are much more important in determining parts allowances than part costs are when the system is relatively well funded.

For both the FLSIP model and the Availability model, the level of availability improves as the systems become more redundant. The general improvement in availability as system redundancy increases is expected from reliability theory. As shown on Table XV, the percentage improvement with the Availability model is much higher than with the FLSIP model. This could also be anticipated since the Availability model is an optimization model which would increasingly enhance the reliability of a system as the system became more and more reliable itself; while the FLSIP model would provide the same level and type of support to

TABLE XIV

Average Availability: Actual MTBF Used to Compute Allowances

(100% Fully Funded Scenarios)

	No Redun						Low Redun					
	FLSIP			AVA			FLSIP			AVA		
MTBF Case	1	2	3	1	2	3	1	2	3	1	2	3
Part Cost Case												
Case A	90	83	83	90	82	83	94	95	89	96	95	98
Case B	90	83	83	90	85	84	94	95	89	96	95	96
Case C	90	83	83	a	85	a	94	95	89	97	98	a

	Med Redun						Hi Redun					
	FLSIP			AVA			FLSIP			AVA		
MTBF Case	1	2	3	1	2	3	1	2	3	1	2	3
Part Cost Variance Case												
Case A	97	99	91	99	99	99	97	99	92	99	99	99
Case B	97	99	91	99	99	99	97	99	92	99	99	99
Case C	97	99	91	99	99	a	97	99	92	99	99	a

a - no optimal solution could be found using the JEE algorithm programmed for this research.

all systems regardless of how reliable the system might be. This results in providing support to components for which additional support is not needed at the expense (tradeoff) of not having extra support in areas which could use it.

TABLE XV

Percent Decrease in Unavailability By Using Availability Allowances Vice FLSIP

Part Cost Var Case	MTBF Var Case	Fund %	No Redun	Low Redun	Med Redun	Hi Redun
A	1	100	Same	28	47	56
		75	Same	28	69	86
		50	Same	6	29	72
B	1	100	Same	28	52	57
		75	3	30	80	27
		50	(9)	8	68	81
C	1	100	NOPT	41	57	57
		75	10	82	87	87
		50	(4)	54	95	95
A	2	100	(8)	3	65	80
		75	9	46	69	48
		50	a	a	89	a
A	3	100	Same	79	94	94
		75	5	60	93	95
		50	4	55	95	95
B	2	100	10	12	78	80
		75	9	27	78	48
		50	a	a	a	a
C	2	100	11	59	84	84
		75	1	53	88	87
		50	a	a	a	a
B	2	100	10	66	94	95
		75	12	49	92	95
		50	3	21	94	95
C	3	100	NOPT	NOPT	NOPT	NOPT
		75	NOPT	NOPT	NOPT	NOPT

Percent Improvement	#	%	#	%	#	%	#	%
50 %	0	0	10	45	21	91	20	90
75 %	0	0	2	9	15	65	16	73
90 %	0	0	0	0	8	35	8	35

a - FLSIP allowances could not be computed at budget constraint specified

NOPT - an optimal solution could not be obtained using the Availability Model

The FLSIP system is designed to have a 90% probability of not running out of a specific part during a 90 day mission. This part availability goal cannot be converted directly to an equipment availability goal; however it is of interest to compare how often systems were available at least 90% of the time under each model. As shown at the bottom of Table XII for average availability, allowances developed using the .25 FLSIP model achieved 90% availability only 50% of the time while allowances developed using the Availability model achieved 90% availability 65% of the time. For instant availability, the .25 FLSIP model achieved 90% availability only 20% of the time while allowances developed using the Availability model achieved 90% availability 52% of the time as shown on Table XIII. The Availability model shows its greatest advantage over FLSIP for cases in which less than 100% funding was available as shown in Figure 5.8.

Average Availability

Funding Level	FLSIP Model	AVA Model
100 %	89 %	100 %
75 %	56 %	83 %
50 %	16%	68%

Figure 5.8 Percentage of Times Allowances Achieved 90% Average System Availability

D. INACCURATE INPUT DATA

One measure of interest when evaluating mathematical models is the "robustness" of the models. That is, how well do the models work when there are deviations from the

assumptions upon which the models are derived. This section examines one such robustness issue. The effectiveness results of the three models are compared for the hypothetical case in which the values input for the MTBF parameters are assumed to be in error. Simulations were run with the 100% funded allowances where the usage rate was assumed to actually be twice as high (MTBF is half as high) as the figures used above to compute the allowances. The results of those simulations are shown on Table XVI.

As before, the effectiveness results are better with the Availability model than with the FLSIP model. However, the improvement afforded by the Availability model is even greater when the MTBF values are lower as shown on Table XVII. In the results summarized in Table XVI, only 17% of the scenarios using FLSIP model allowances achieved an equipment availability of 90% or better while more than 44% of the scenarios using Availability model allowances achieved the 90% criteria. The better performance of the Availability model in this situation is to be expected since it will focus support on those items which are most critical to the operation of the system at the expense of those components which are redundant. Then, since repair parts are concentrated in the critical components, failures more frequent than expected will not have as serious effect on system availability in contrast to the FLSIP model which attempts to cover all the bases.

Repair parts allowances determined using the Availability model often resulted in a smaller range of repair parts being carried than under the FLSIP model. This was particularly true when a severe budget constraint was imposed. For example, the unconstrained .25 FLSIP allowances and the Availability allowances for System D with Case B Part Costs and Case 2 MTBFs are shown in Figure 5.9. Both

TABLE XVI

Inaccurate MTBF Data: Percent System Availability Achieved

Average Availability

Part Cost Var Case	MTBF Var Case	Fund %	No Redun		Low Redun		Med Redun		Hi Redun	
			FLSIP	AVA	FLSIP	AVA	FLSIP	AVA	FLSIP	AVA
A	1	100	61	61	73	84	58	74	86	98
B	1	100	61	61	73	82	58	80	86	97
C	1	100	61	a	73	91	58	92	86	98
A	2	100	54	54	77	83	96	99	97	99
A	3	100	52	55	65	92	76	99	77	99
B	2	100	54	58	77	79	95	99	97	99
C	2	100	54	59	77	89	95	99	97	99
B	3	100	52	53	65	82	76	99	77	99
C	3	100	52	a	65	a	76	a	77	a
Percentage Achieving 90%			-0-	-0-	-0-	25	33	75	33	100

Instant Availability

Part Cost Var Case	MTBF Var Case	Fund %	No Redun FLSIP	No Redun AVA	Low Redun FLSIP	Low Redun AVA	Med Redun FLSIP	Med Redun AVA	Hi Redun FLSIP	Hi Redun AVA
A	1	100	10	10	26	51	4	24	56	96
B	1	100	10	10	26	48	4	34	56	96
C	1	100	10	a	26	78	4	79	56	98
A	2	100	9	9	36	52	84	99	92	99
A	3	100	4	5	20	77	42	96	47	99
B	2	100	9	11	36	40	83	99	93	99
C	2	100	9	13	36	66	83	99	93	99
B	3	100	5	5	20	46	42	99	47	99
C	3	100	5	a	20	a	42	a	47	a
Percentage Achieving 90%			-0-	-0-	-0-	-0-	-0-	63	33	100

Summary: Average Availability: FLSIP 6/36 = 17%
AVA 14/32 = 44%

Instant Availability: FLSIP 3/36 = 8%
AVA 13/32 = 41%

a - no optimal solution could be found using the Availability formula

TABLE XVII

Inaccurate MTBF Data: Percent Decrease in Unavailability

Percent Decrease in Unavailability Using
Availability Model Instead of FLSIP Model

Average Unavailability

Part Cost Var Case	MTBF Var Case	Fund %	No Redun	Low Redun	Med Redun	Hi Redun
A	1	100	Same	39	39	82
B	1	100	Same	34	53	82
C	1	100	NOPT	66	82	84
A	2	100	Same	28	83	90
A	3	100	9	76	94	96
B	2	100	9	10	87	91
C	2	100	11	55	92	90
B	3	100	5	48	95	96
C	3	100	NOPT	NOPT	NOPT	NOPT

Instant Availability

Part Cost Var Case	MTBF Var Case	Fund %	No Redun	Low Redun	Med Redun	Hi Redun
A	1	100	Same	34	21	92
B	1	100	Same	30	31	92
C	1	100	NOPT	71	78	96
A	2	100	Same	25	94	97
A	3	100	1	71	94	98
B	2	100	2	5	93	99
C	2	100	4	47	99	75
B	3	100	1	32	97	99
C	3	100	NOPT	NOPT	NOPT	NOPT

NOPT - no optimal solution could be found using the Availability formula

of the above allowances cost exactly $1700.00. The FLSIP allowance resulted in average availability of .9925 while the Availability model allowances resulted in average availability of .9985; so that slightly better availability was achieved with only half the number of line items stocked by the Availability model. This phenomenon is not peculiar to this one case. The Availability model calculated fewer line items than the FLSIP model for every scenario in which the

system being evaluated had any designed-in redundancy. It also calculated fewer line items than the FLSIP model for about one-third of those systems which had no built in redundancy. These results show that separate range and depth calculations are not necessarily needed in repair parts allowance determination models. The single criteria used by the Availability model implicitly excludes many items from range consideration by assigning them an allowance quantity of zero. The Marginal Analysis model reviewed in this research does the same thing.

	Part Number							
Allowance Model	1	2	3	4	5	6	7	8
FLSIP	1	4	2	1	1	1	1	1
Availability	5	0	0	0	0	3	4	4

Figure 5.9 System D Allowances

VI. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. SUMMARY

The NAVSEA TIGER simulation model was modified in this thesis for use in evaluating three allowance determination models: the FLSIP model, the Marginal Analysis model, and the Availability model. The FLSIP model was originally included as part of the TIGER model so that FLSIP repair part allowances could automatically be computed if desired. Subprograms were written for this thesis so that repair parts for the other two models could automatically be computed by the TIGER model also. The modifications to the TIGER model made by Leather [Ref. 1: p.1] were utilized as well as his recommendation for converting BRF data into MTBF data for use in the TIGER model. The allowance computations and simulations were run on the IBM System 3033 located at the Naval Postgraduate School.

Four sample systems with varying degrees of designed-in redundancy were used to evaluate the effectiveness of the allowance determination models. Different combinations of unit cost and MTBF data were also used to evaluate the relative importance of these data elements in each of the models. And finally, different levels of funding availabilities were used to evaluate the robustness of each model with respect to funding constraints.

The effectiveness of each model for every system and scenario was obtained at three funding levels. First, the effectiveness of each model for each system/scenario combination was determined using a budget constraint equal to the cost of the allowances determined using an unconstrained .25 FLSIP model. Then the effectiveness of each model for each

system/scenario combination was determined using 75% and then 50% of the original amount.

The effectiveness of the allowance determination models was measured by the simulated availability of the systems being supported. The measures of effectiveness used were:

$$\text{Average availability} = \frac{\text{Summation of Uptime for All Missions Simulated}}{\text{Summation of Total Mission Calender Time for all Missions Simulated}}$$

$$\text{Instant availability} = \frac{\text{Number of Missions Up at Time (t)}}{\text{Total Number of Missions Simulated}}$$

B. CONCLUSIONS

The Marginal Analysis model was not found to be significantly more effective than the FLSIP model and was decidedly less effective than the Availability model from an overall perspective. The Availability model was always at least as effective as the FLSIP model and it significantly outperformed the FLSIP model where funding constraints precluded 100% funded FLSIP allowances and where the MTBF were reduced by 50% to simulate a case of inaccurate failure rate data.

It was observed that changing the FLSIP cut point is not an effective method for accommodating budget constraints in systems with mostly high failure rate components. The FLSIP cut point is the dividing line between those low demand items which should be protected by an "insurance" allowance and those which should not. However, if all or most of the parts in a system have high enough demands to qualify for stocking on a demand based criteria, then changing the FLSIP cut point will not effect the number of these parts carried and therefore cannot be used to accommodate budget constraints. Use of the Availability model is a much more

effective method for accommodating budget constraints in these situations.

There was no significant difference in the effectiveness of systems supported by FLSIP determined allowances and Availability determined allowances when the system was non-redundant. As system redundancy increased, the availability improved for both FLSIP and Availability allowances. However, the magnitude of the improvement was significantly greater with the Availability allowances.

Fully funded .25 FLSIP allowances resulted in 90% system availability only 50% of the time even though the repair parts carried should theoretically have been sufficient to satisfy 90% of all repair part requests. Availability allowances at the same level of funding achieved 90% availability 65% of the time.

Repair part allowances determined using the Availability model often resulted in a smaller range of repair parts carried than did the FLSIP model. This was particularly true when a severe budget constraint was imposed. Finally, the Availability model incorporates both a range and depth capability illustrating that separate range and depth criteria are not required in all allowance determination models.

C. RECOMMENDATIONS

1. Further analysis of the Marginal Analysis model used in this research is not justified. Other marginal analysis models may be better and could be investigated in the same manner because of the ease in obtaining and entering the minimal amount of data required for this type of model.

2. System availability should be used as the measure of effectiveness for shipboard allowance determination models. This would require that a "standard" of effectiveness be

defined. If the present FLSIP system meets the established availability goals then no further development of allowance determination systems would be required. On the other hand, if the present FLSIP system does not meet the established goals, then further development of an improved allowance determination system would be justified.

3. The use of the Availability model for determining shipboard repair part allowances should be further investigated. The importance of the various variables in the Availability model should be clarified. For example, is an improvement in repair time more important than an improved set of repair part allowances or are actual repair times really needed at all? The types of systems where availability can be improved the most should also be determined; ie. systems with mostly high failure rate parts or low failure rate parts, systems with many components or only a few components, systems with a lot of designed in redundancy or only a little redundancy, etc. The TIGER simulator could be used to evaluate these various factors on a detailed basis.

4. The TIGER simulator or an improved version of a follow-on simulator should be used to evaluate the relative importance of the major factors in the shipboard operating environment which influence system availability (ie. inaccurate MTBF reporting, configuration data, etc.). The TIGER simulator is easy to understand and easy to use. Once input data has been prepared, an allowance computation and simulation of 1000 missions can be run interactively on an IBM 3033 in two to six seconds of computer time. For example, it could be used to evaluate the effect of having bad BRF data when computing shipboard allowances using the FLSIP procedures to see how much emphasis should be placed on

obtaining better data. If equipment availability is relatively insensitive to inaccurate BRF data, then the improvement of data collection techniques can be ignored. If equipment availability is seriously degraded when BRF data is lower than actual failure rates, then the development of improved data collection techniques should be given a high priority. The TIGER simulator could also be used to evaluate what other factors in the logistics system are most pertinent in achieving better equipment availability so that emphasis can be placed on developing allowance determination models that include those important factors instead of factors that are less influential.

APPENDIX A

ACRONYMS

BRF	Best Replacement Factor
FLSIP	Fleet Logistics Support Improvement Program
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
NAVSEA	Naval Sea Systems Command
POP	Item Population
SPCC	Navy Ships Parts Control Center

APPENDIX B

AMENDED TIGER PROGRAM INPUT REQUIREMENTS

The punched cards or card images discussed in this appendix must be input to utilize the NAVSEA TIGER program as amended for this research effort. A complete printout of the amended program is provided in Appendix C.

Card Type 1. Availability Model Processing Cards.

The Availability Model Processing Cards control the order in which the various parts in a system will be combined to compute optimal repair part allowances for the system when the Availability Model is being used. The first step in preparing this card is to complete a system reliability block diagram similar to Figure B.1.

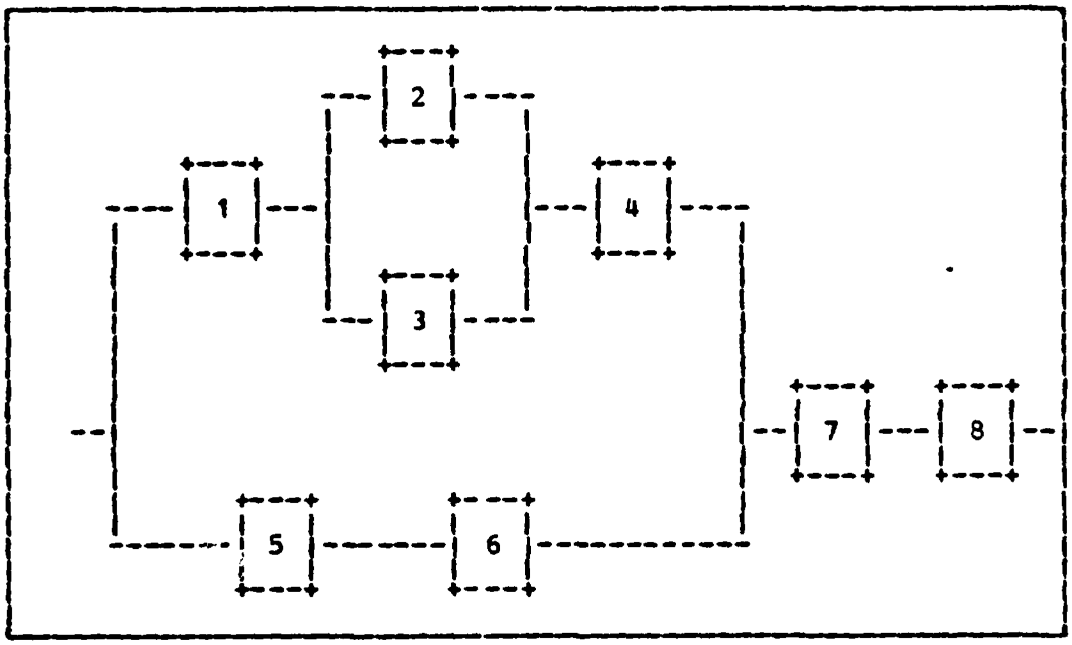

Figure B.1 Block Diagram Example

Once an accurate reliability block diagram has been prepared, the system availabilities resulting from combining all the individual parts must be computed. This is done by starting with two parts and progressively combining additional parts until all of the parts have been combined. To properly prepare the Availability Model Processing Cards, the system must be analyzed to determine how the individual

components can be combined so that there are never more than two sets of parts combinations. For example, the parts in the system in Figure B.1 could be combined in the following manner:

```
     Combination #1 = (Part 2) and (Part 3)

Next Combination #1 = Previous Combination #1 and
                      (Part 1)

                    = (Parts 2,3) and (Part 1)

Next Combination #1 = Previous Combination #1 and
                      (Part 4)

                    = (Parts 1,2,3) and (Part 4)

     Combination #2 = (Part 5) and (Part 6)

Next Combination #1 = Previous Combination #1 and
                      Previous Combination #2

                    = (Parts 1,2,3,4) and (Parts 5,6)

Next Combination #2 = (Part 7) and (Part 8)

Next Combination #1 = Previous Combination #1 and
                      Previous Combination #2

                    = (Parts 1,2,3,4,5,6) and
                      (Parts 7,8)
```

They could not be combined in the following manner even though the parts combinations are appropriate because the use of three combinations is not allowed:

```
       Combination #1 = (Part 2) and (Part 3)

  Next Combination #1 = Previous Combination #1 and
                        (Part 1)
                      = (Parts 2,3) and (Part 1)

  Next Combination #1 = Previous Combination #1 and
                        (Part 4)
                      = (Parts 1,2,3) and (Part 4)

       Combination #2 = (Part 5) and (Part 6)

       Combination #3 = (Part 7) and (Part 8)

  Next Combination #2 = Previous Combination #2 and
                        Previous Combination #3
                      = (Parts 5,6) and (Parts 7,8)

  Next Combination #1 = Previous Combination #1 and
                        Previous Combination #2
                      = (Parts 1,2,3,4) and
                        (Parts 5,6,7,8)
```

Once an appropriate flow of combinations has been determined for a system, the worksheet shown on Figure B.2 should be prepared. The first spares to be combined will be shown next to combination 101. In addition, whether they are to be in series or parallel must be coded and all the parts included in the resulting combination should be specified. The next line will show the part number or combination number for the parts being combined in that step, whether they are in series or parallel, and which

Comb #	Part or Combin	Part or Combin	Ser (1) Par (0)	Parts Included
101				
102				
103				
104				
105				
106				
107				
108				
109				
110				
111				
112				
113				
114				
115				
116				
117				
118				
119				
120				
121				
122				
123				
124				
125				

Figure B.2 Availability Model Processing Card Worksheet

parts end up being included in that combination. This process is continued until all parts are included in the last combination. An example of a worksheet filled in for the proper combination of parts in Figure B.1 discussed above is shown in Figure B.3.

An individual Availability Processing Card must then be prepared for each line on the worksheet (in the format provided below). The cards must be input in the same order they appear on the worksheet. One additional card must be added at the end of this deck which has zeros in columns 4, 8 and 12 to signify that all combinations are complete. If the Availability model is not being used, these cards can be left in the input data or only the last card with the three zeros can be input.

Comb #	Part or Combin	Part or Combin	Ser(1) Par(0)	Parts Included
101	2	3	0	2,3
102	101	1	1	1,2,3
103	102	4	1	1,2,3,4
104	5	6	1	5,6
105	103	104	0	1,2,3,4,5,6
106	7	8	1	7,8
107	105	106	1	1,2,3,4,5,6 7,8

Figure B.3 Example of Worksheet

The format and content of the individual cards are shown below. Note that only the 3 middle columns of Figure B.3 are entered. An example of the cards prepared from Figure B.3 is shown in in Figure B.4.

Columns	Format	Variable Name	Description
1-4	I4	J	The first of two parts or combinations to be combined for determining optimum combination of spares using the JEE algorithm.
5-8	I4	K	The second of two parts or combinations to be combined for determining optimum combination of spares using the JEE algorithm.
9-12	I4	SER	Indicates whether two systems being compared on this card are in series (set SER = 1) or in parallel (set SER = 0).

```
Card Columns:
         1111111111222222222233333333334444444444555
123456789012345678901234567890123456789012345678901
   2   3   0
 101   1   1
 102   4   1
   5   6   1
 103 104   1
   7   8   1
 105 106   1
   0   0   0
```

Figure B.4   Cards for Worksheet in Figure B.3

Card Type 2. Allowance Model Card.

This card is used to determine which allowance determination model is to be used to compute repair parts and to input budget data. The format and content of the individual cards are shown below. An example of this card for the system in Figure B.1 for FLSIP processing and a budget of $3,000.00 is shown in Figure B.5.

Columns	Format	Variable Name	Description
1-4	I4	NTOTA	Total number of parts in the system (must equal number of cost cards entered below). If cost cards are not to be entered, use 1 in card column 4 and include 1 cost card with a $1.00 cost.
5-8	F4.0	XFLAG	Used to select type of allowance determination system as follows: - "0.0" for FLSIP - "1.0" for Marginal Analysis - "2.0" for Availability
9-16	F8.0	BUDGET	Budget to be used for computations. Max budget allowed is $99,999,999.00.

```
Card Columns:
         1111111111222222222233333333334444444444555
1234567890123456789012345678901234567890123456789012
   8 0.0 3000.00
```

Figure B.5 Allowance Model Card Example

Card Type 3. Cost Cards.

A separate Cost Card must be entered for each part in the format specified below. An example of these cards for the system in Figure B.1 is given in Figure B.6.

Columns	Format	Variable Name	Description
1-8	F8.2	Cost	Cost of each repair part. Costs must be input in the same order as equipment type numbers on Equipment Type cards. Total cards must equal NTOTA on Allowance Model Processing card. If cost data is not to be entered, use one card with a cost of $1.00.

```
Card Columns:

         1111111111222222222233333333334444444444555
1234567890123456789012345678901234567890123456789012
100.00
100.00
150.00
500.00
2000.00
50.00
300.00
1000.00
```

Figure B.6 Cost Card Examples

Card Type 4. JEE Data Card.

The total mission time and the maximum number of spares allowed for each repair part must be input in the format described below. An example of a JEE Data card for the system in Figure B.1 is shown in Figure B.7 using a 90 day mission time (90 X 24 = 2160) and a maximum number of spares equal to nine.

Columns	Format	Variable Name	Description
1-8	I8	JTIME	Total Mission Time.
9-12	I4	TOTSPR	Total number of spares for which availability is to be computed using the availability model. Max is 9. If Availability model is not to be used, insert 1 in card column 12.

```
Card Columns:
                 1111111111222222222233333333334444444444555
        123456789012345678901234567890123456789012345678901 2
            2160    9
```

Figure B.7 JEE Data Card Example

Card Type 5. Timeline Iteration Card

The number of timeline iterations to be used and the run identification data for the specific run being made are shown on this card. A timeline iteration of one was used for all the simulations done for this research. Additional information for using more than one timeline iteration may be fcund in refernce 4, section 2. The format is described below. An example of a Timeline Iteration Card for the system in Figure B.1 is shown in Figure B.8.

Columns	Format	Variable Name	Description
1-4	I4	JCC	Number of timeline iterations to be run for the data deck.
5-80	19A4	RUNID	Alphanumeric run identification information.

```
Card Columns:
                 1111111111222222222233333333334444444444555
        1234567890123456789012345678901234567890123456789012

           1 .25 FLSIP RUN FOR SYSTEM B1 ON 5/20/82
```

Figure B.8 Timeline Iteration Card Example

Card Type 6. Statistical Parameter Card.

Statistical parameters for the run are entered on this card. If a predefined fixed number of missions is to be run, set PL = 1.0 and NOPT and NMAX to the desired number of missions. All simulations for this research were run with a fixed number of 1000 missions. If what is desired is to determine whether a system meets a certain level of reliability, that level can be specified in the PL and XK blocks and the simulator will run an adequate number of missions to determine whether the system will meet or fail to meet the specified reliability (PL) within the standard deviation specified (XK) [Ref. 4: p. 2-7]. An example of a Statistical Parameter Card for use with the system in Figure B.1 is shown in Figure B.9.

Columns	Format	Variable Name	Description
1-4	I4	NMAX	Maximum number of missions to be run (should be in multiples of 50 and must not exceed 1000).
5-8	I4	NOPT	Optimal number of missions (not to exceed NMAX).
9-12	F4.0	PL	Specification requirement for reliability.
13-16	F4.0	XK	Standard deviation to be used in calculating lower control limit. A value of 1.28 corresponds to a 90% lower confidence limit.
17-20	I4	ISEED	Random number seed.
21-24	I4	NPH	Number of phase types - not to exceed 6.

```
Card Columns:
                1111111111222222222233333333334444444444555
       1234567890123456789012345678901234567890123456789012

       10001000 1.01.282222    1
```

Figure B.9   Statistical Parameter Card Example

Card Type 7. Phase Type and Duration Cards.

This card is used to specify the number of phase types and how long each is to last. The phases can be used to identify different scenarios. For example, for simulating shipboard operations: one phase can represent in-port periods, another can represent normal steaming operations, and a third can represent battle engagement periods. The repair option for each part can be different in each phase as specified on Card Type 10 and the Duty Cycle Utilization of each part can also be different during each phase as specified on Card Type 12. From 1 to 95 phase sequences of not more than six phase types can be specified on these cards. The format for this card is described below. For this research effort, a single phase lasting 90 days (2160 hours) was used for all simulations. An example of this type card is shown in Figure B.10.

Columns	Format	Variable Name	Description
1-2	F2.0	XXT(1)	Phase type number for first simulation sequence.
3-10	F8.0	XXT(2)	Duration of first sequence.
11-12	F2.0	XXT(3)	Phase type number for second simulation sequence (if any).
13-20	F8.0	XXT(4)	Duration of second phase.
21-22	F2.0	XXT(5)	Phase type number for third simulation sequence (if any).
23-30	F8.0	XXT(6)	Duration of third sequence.
31-32	F2.0	XXT(7)	Phase type number for fourth simulation sequence (if any).
33-40	F8.0	XXT(8)	Duration of fourth sequence.
41 42	F2.0	XXT(9)	Phase type number for fifth simulation sequence (if any).
43-50	F8.0	XXT(10)	Duration of fifth sequence.

Note: If more than 5 phase sequences are needed, continue on additional cards using the same fields. No more than 95 phase sequences are permitted.

```
Card Columns:
                 1111111111222222222233333333334444444444555
1234567890123456789012345678901234567890123456789012
1.2160.
```

Figure B.10 Phase Type and Duration Card Example

Card Type 8. ***** Blank Card *****

Card Type 9. Printout Option Card

This card is used to select which printout option is to be used. The format is as follows.

Columns	Format	Variable Name	Description
1-4	I4	KOPT	Printout option switch
			= 1 for management summary
			= 2 for engineering summary
			= 3 for complete details (used for debugging only)
			= 4 to suppress printout of input data
			= 5 to specify printout using KS variables below
			= 6 for TIGER/MANNING complete details (debugging only)

If KOPT 5 is used, select from the following output options as needed (otherwise leave the fields blank):

Columns	Format	Variable Name	Description
5-8	I4	KS(1)	= 1: Input data
9-12	I4	KS(2)	= 1: equipment down at time of mission failure
13-16	I4	KS(3)	= 1: down time at end of phase
17-20	I4	KS(4)	= 1: abort messages
21-24	I4	KS(5)	= 1: all events
25-28	I4	KS(6)	= 1: ETIME matrix
29-32	I4	KS(7)	= 1: not used
33-36	I4	KS(8)	= 1: not used
37-40	I4	KS(9)	= 1: not used
41-44	I4	KS(10)	= 1: system & subsystem status
45-48	I4	KS(11)	= 1: TIGER/MANNING debugging
49-52	I4	KS(12)	= 1: status of all groups
53-56	I4	KS(13)	= 1: downtime message

Card Type 10. Phase Repair Card

This card is used to specify the repair option for each phase up to a total of six. The format is as follows:

Columns	Format	Variable Name	Description
1-4	I4	IFLAG(1)	Repair option for each phase type (up to 6): = 0 if on-board repair allowed in the phase = 1 if no on-board repair allowed in the phase = 2 if on-board repair allowed but failure inhibited
5-8	I4	IFLAG(2)	
9-12	I4	IFLAG(3)	
13-16	I4	IFLAG(4)	
17-20	I4	IFLAG(5)	
21-24	I4	IFLAG(6)	

Card Type 11. Repair Policy Card.

This card is used to establich repair policy for the simulation being run. REPOL determines what percentage of repairs will be made at the shipboard level as opposed to the intermediate and depot level. Since this research evaluates shipboard support only, REPOL was set equal to 1.0 for all simulations.

A part can be allowed to fail for a certain period of time before its failure causes the system to be in a down status by specifying an allowable downtime in the TAD2 field. For this research, all missicn allowable downtimes were set equal to zero.

Specified MTBFs and MTTRs can be changed for a given simulation run by using a value other than 1.0 in the XM and XT fields.

The format for the card is:

Columns	Format	Variable Name	Description
1-4	F4.0	REPOL	Decimal fraction of repairs to be performed aboard ship
5-12	F8.2	TAD2	Mission Allowable Downtime
13-16	F4.0	XM	MTBF Multiplier. Default = 1.0
17-20	F4.0	XT	MTTR Multiplier. Default = 1.0

Card Type 12. Equipment Type Cards

Equipment type cards are used to input the specific parameters for each type of equipment (repair part) being evaluated. A seperate card must be input for each type of equipment. The TIGER simulator can accomodate various equipment operating rules and variable duty cycles for each piece of equipment (these options were not utilized for this research). A detailed discussion of these items can be found in Reference 4, chapter 2. The format for these cards is provided below. An example of these cards for the system in Figure B.1 is shown in Figure B.11.

Columns	Format	Variable Name	Description
1-4	I4	I	Equipment type numbers-should be assigned sequentially starting at 1, not to exceed 200.
5-20	4A4	F1	Equipment type description
21-28	F8.0	XMTBF	Mean Time Between Failure
29-32	F4.0	XMTTR	Mean Time to Repair/replace Non-repairable is indicated by 9999.
33-36	F4.0	U	Duty cycle utilization (non-zero decimal fraction.
37-40	F4.0	V	Administrative delay time from tender to ship
41-44	F4.0	W	Administrative delay time from depot to ship.
45-48	I4	IUI	Used for variable duty cycles. See Reference 4, chapter 2 for an explanation.

```
Card Columns:

                 1111111111222222222233333333334444444444555
        1234567890123456789012345678901234567890123456789012
           1 PART 1           25000.0  10.01.0
           2 PART 2            1500.0  10.01.0
           3 PART 3             750.0  10.01.0
           4 PART 4             750.0  10.01.0
           5 PART 5            1500.0  10.01.0
           6 PART 6            7500.0  10.01.0
           7 PART 7            7500.0  10.01.0
           8 PART 8            2500.0  10.01.0
```

Figure B.11   Examples of Equipment Type Cards

Card Type 13. Variable Duty Cycle (VDC) Card.

This is an optional card. It is used if variable duty cycles are used. See chapter 2 of Reference 4 for details of its use.

Card Type 14. Variable Mean Time to Repair Card.

This is an optional card. It is used if variable Mean Times to Repair are used. See chapter 2 of Reference 4 for details of its use.

Card Type 15. ***** Blank Card *****

Card Type 16. Equipment Cards.

Each individual piece of equipment (repair part) in the system being evaluated must be given a unique number to identify it. These cards identify which equipment type each specific equipment (repair part) is. There must be one card for each equipment type and they must be input sequentially by equipment type number in the format specified below. For this research, the aspects of spares sharing were not considered because the calculations developed by JEE [Ref. 3], are different for scenarios where spares are shared. To use the Availability model developed for this research, each equipment number must be assigned its own equipment type even if the parameters for two or more equipments are identical.

Columns	Format	Variable Name	Description
1-4	I4	NTYPE	The type number associated with the equipment listed in the next field or fields.
5-8	I4	LOAD(1)	Equipment numbers of those equipment which belong to the designated equipment type - up to 19 equipment per card (if there are more than 19 equipment associated with a given type, use additional equipment cards and repeat the same type number). The largest equipment number allowed by the program is 500. The total number of equipments must not exceed 500. No gaps are allowed between equipment 1 and the largest assigned equipment number.
9-12	I4	LOAD(2)	
13-16	I4	LOAD(3)	
17-20	I4	LOAD(4)	
21-24	I4	LOAD(5)	
25-28	I4	LOAD(6)	
29-32	I4	LOAD(7)	
33-36	I4	LOAD(8)	
37-40	I4	LOAD(9)	
41-44	I4	LOAD(10)	
45-48	I4	LOAD(11)	
49-52	I4	LOAD(12)	
53-56	I4	LOAD(13)	
57-60	I4	LOAD(14)	
61-64	I4	LOAD(15)	

65-68	I4	LOAD(16)
69-72	I4	LOAD(17)
73-76	I4	LOAD(18)
77-80	I4	LOAD(19)

Card Type 17. ***** Blank Card *****

Card Type 18. Spares Model Card.

This card is used to specify whether spares will be input directly or whether spares will be computed using one of the allowance determination models. The options for this card are:

a) Use the literal "Unlimited Spares" in columns 1 through 16 to simulate unlimited spares. The program then assigns 90,000 spares for each equipment or repair part. This option was not used during this research.

b) Use a blank card if spares are going to be specified. Then input the desired number of spares for each equipment or repair part on the spares cards which follow. (This option was used to simulate the use of inaccurate MTBF data by computing allowances with one set of MTBF data and then specifying those allowances using this option and inputting different MTBF parameters for comparison.) If spares have been specified and the effect of using a different level of support are needed, this effect can be obtained by inserting a spares multiplier (SX) in card columns 21 to 24 of this card. The program will then use the number of spares assigned times the spares multiplier specified.

c) Use "999." in columns 21 to 24 to use the allowance determination model specified on the Allowance Model card (Card Type 2).

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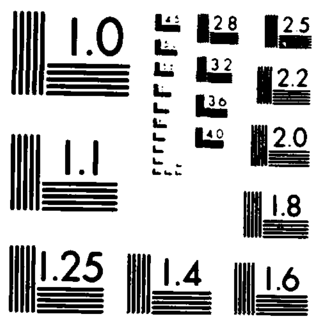
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Card Type 19. Spares Cards.

These cards are only used if the allowances for spares are going to be specified exactly (columns 1 through 16 of the Spares Model card must be empty and columns 21 through 24 must have something other than .999). One of these cards must be input for each equipment type being used. These cards must be input in order starting with Equipment Type 1 in the following format:

Columns	Format	Variable Name	Description
1-4	I4	ISPARE(1)	Number of organizational level spares (on board) for the equipment type.
5-8	I4	ISPARE(2)	Number of spares at the tender for the equipment type.
9-12	I4	ISPARE(3)	Number of spares at the base (depot) for the equipment type

///

NOTE: For each phase type, a set of the remaining cards (except the optional output and demo decks which appear once) must be placed consecutively in the data deck.

///

A separate reliability block diagram must be prepared for the simulation runs on the TIGER simulator. It is different than the reliability block diagram previcusly discussed for Availability model processing because it does not have to relate only two groups at a time. For the TIGER simulator, equipments must be aggregated into systems, subsystems, and groups. A system is a set of equipments for which availability is being measured. A subsystem is a set of equipments which, if the set fails, will cause the system to fail. A group is any set of equipments.

For the reliability block diagram for the TIGER simulator, each parallel subset of equipment and each series subset are assigned group numbers. For the example shown in Figure B.1, the groups could be as shown below. Group numbers must be between 501 and 1000 and are arbitrarily assigned below.

Group Number	Equipments in Group	Series/Parallel
501	2 and 3	Parallel
502	5 and 6	Series
503	7 and 8	Series

Once each subset of parallel or series equipments has been assigned a group number, the identified groups are then aggregated into groups of groups which are in parallel or series and these groups are assigned numbers. For the equipments in Figure B.1, the next set of groups could look like those shown below.

Group Number	Equipments in Group	Series/Parallel
601	1,4, and 501	Series
701	502 and 601	Parallel
888	503 and 701	Series

This process is continued until all the parts in the system can be identified in one group (known as a subsystem group). The subsystem groups are then combined with any remaining equipment which are in series and assigned a final group number (known as the system group). For our example, Group # 701 would be a subsystem group and the system group would be composed of subsystem group # 701 and the series group # 503. For illustrative purposes, the system group will be assigned Group number 888. The method for inputing these relationships into the TIGER simulator are discussed under card types 20 through 23.

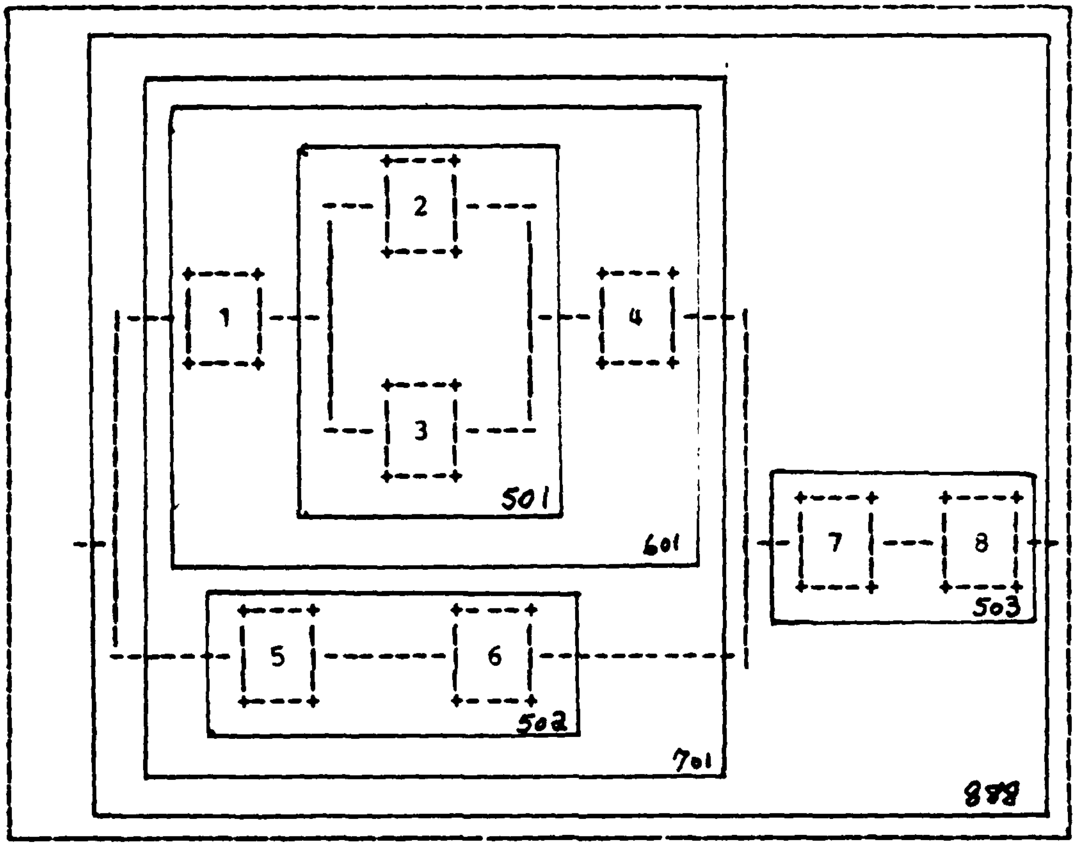

Figure B.12 Example of System, Subsystem, and Group Numbering

Card Type 20. System Card.

This card is used to identify the different systems being evaluated. The format for this card is as follows:

Columns	Format	Variable Name	Description
1-4	A4	ID	Any alphanumeric (ie. the literal "SYST") used to identify the specific system
5-8	I4	LL	Phase type number (sequential) The max value is 6.
9-12	I4	NSS	Number of subsystems in phase (varies only from 1 to 31).
13-16	I4	ISS	System identification number (usually last group number on the configuration matrix cards).
17-24	F8.0	SSTIME	System allowable sustained down time (should not be less than subsystem TAD1 values). Should be less than or equal to TAD2 (repair policy card). To inhibit aborts use a value of 100,000.

An example of the System Card for the system in Figure B.12 is:

```
Card Columns:

         111111111122222222223333333333444444444455
123456789012345678901234567890123456789012345678901

SYST   1   1 888     0.0
```

Card Type 21. Subsystem Cards.

This card is used to identify the different subsystems being evaluated. The format for this card is as follows:

Columns	Format	Variable Name	Description
1-4	A4	ID	Any alphanumeric (ie. the literal "SS1").
5-8	I4	LL	Phase type number.
13-16	I4	ISS	Subsystem identification number. This is a group number for a group defined on a configuration matrix card (see below). Each designated subsystem group must be a group that, upon its failure, causes the system to fail.
17-24	F8.0	SSTIME(2)	Subsystem allowable sustained downtime (TAD1). This value should be less than or equal to SSTIME on the system card. To inhibit aborts use a value of 100,000.

An example of the Subsystem Card for the system in Figure B.12 is:

```
Card Columns:
         1111111111222222222233333333334444444444455
1234567890123456789012345678901234567890123456789012345678901
 551    1      701      0.0
```

Card Type 22. Configuration Matrix Cards.

This card is used to identify the different groups in the systems being evaluated. The format for these cards is as follows:

Columns	Format	Variable Name	Description
1-4	I4	NRO	The number of members in the group defined on this card that are required to be operational and in an up state.
5-8	I4	IB(1)	The group number assigned to the group of members defined on this card. It may vary from 501 to 1000.
9-12	I4	IB(2)	The numbers of the equipment and groups which make up the group defined on this card. The max number of members in a group is unlimited; however, if there are more than 7, a continuation card is required, which is of the same format. The number required and master group number must be identical on all continuation cards.
13-16	I4	IB(3)	
17-20	I4	IB(4)	
21-24	I4	IB(5)	
25-28	I4	IB(6)	
29-32	I4	IB(7)	
33-36	I4	IB(8)	

An example of the Configuration Matrix Cards used for the system in Figure B.12 is:

```
Card Columns:
         1111111111222222222233333333334444444444455
1234567890123456789012345678901234567890123456789012345678901

   1 501   2   3
   2 502   5   6
   1 503   7   8
   3 601   1   4
   1 701 502 601
```

Card Type 23. Equipment Operating Rule Cards.

Operating rules can be specified which will turn selected equipments on and off in predetermined situations. These operating rules were not utilized during this research. All equipments ran all of the time except when they were inoperable. A detailed discussion of the use of this option can be found in Reference 4, chapter 3.

Card Type 24. ***** Blank Card *****

Card Type 25. Optional Output Card.

Optional output tables can be selected by using this card as shown below.

Columns	Format	Variable Name	Description
1-4	A4	SPRS	Place any alphanumeric (ie. "SPR") in this field if a table of spares usage is desired.
5-8	A4	APPL	Place any alphanumeric (ie. "APL") in this field if a summary table of equipment that caused mission failures and system downtimes is desired.
9-12	A4	GMMA	Place any alphanumeric (ie. "GMA") in this field if the gamma distribution output is desired.
13-16	A4	DEMO	Place any alphanumeric (ie. "DEMO") in this field if a sequential probability ratio test plan for the system being analyzed is desired. If this option is excercised, an additional card, 26, is required.

Card Type 26. DEMO Information Card.

This card must be included if DEMO is specified on the Optional Output Card. A detailed discussion of the DEMO Option is provided in Reference 4, chapter 3. The format for this card is as follows:

Columns	Format	Variable Name	Description
1-4	F4.0	A	Producer Risk.
5-8	F4.0	B	Consumer Risk.
9-12	F4.0	R	Discrimination Ratio.
The following are optional inputs.			
13-16	F4.0	HAD	X-axis accept intercept (Delta
17-20	F4.0	HRD	X-axis reject intercept (Delta
21-24	F4.0	YD	Trucation line accept (Delta)
25-28	F4.0	SLD	Slope (Delta)
29-32	I4	KD	Truncation line reject (Delta)
33-36	I4	ITIME	Number of sets
37-40	I4	ITER	Number of simulations per set
41-44	I4	N	Random number initializer

The total input required for the system in Figure B.12 is shown in Figure B.13.

```
    2     3     0      -----
  101     1     1           |
  102     4     1           |
    5     6     1           |-- Availability Model Processing
  103   104     0           |   Cards
    7     8     1           |
  105   106     1           |
    0     0     0      -----
    8 0.03000.00          --------------Allowance Model Card
100.00             ------------
100.00                         |
150.00                         |
500.00                         |--Cost Cards
2000.00                        |          Timeline Iteration
50.00                          |                       Card
300.00                         |     JEE Data Card      |
1000.00            ------------                |        |
   2160     9         -------------------------         |
    1 .25  FLSIP RUN FOR SYSTEM B1 ON 5/20/82  ------
1000 1000  1.  1.282222    1 ---Statistical Parameter Card
1. 2160.           -------------Phase Type and Duration Card

    1              -------------------Printout Option Card
    0              ----------------------Phase Repair Card
1.0 0.0       1.  1.       ------------Repair Policy Card
    1ITEM A                  25000.010.01.0      ----
    2ITEM B                   1500.010.01.0          |
    3ITEM C                    750.010.01.0          | Equipment
    4ITEM D                    750.010.01.0          |--Type
    5ITEM E                   1500.010.01.0          |  Cards
    6ITEM F                   7500.010.01.0          |
    7ITEM G                   7500.010.01.0          |
    8ITEM H                   2500.010.01.0      ----

    1    1              --------------------
    2    2                                  |
    3    3                                  |
    4    4                                  |--Equipment
    5    5                                  |  Cards
    6    6                                  |
    7    7                                  |
    8    8              --------------------

                              999.  .25      ---Spares Model Card
SYST     1    4  999  100000.                ---------System Card
SS1      1       501  100000.            ------
SS2      1       502  100000.                  |---Subsystem Cards
SS3      1       503  100000.                  |
SS4      1       504  100000.            ------
    2  501    3    4                     --------
    2  502    5    6                             |
    1  503  501  502                             |---Configuration
    5  504    1    2  503    7    8              |   Matrix Cards
    1  999  504                          --------

SPRSAPPL                   -----------Optional Output Card
```

Figure B.13   Complete TIGER Program Input Example

APPENDIX C

AMENDED NAVSEA TIGER SIMULATION PROGRAMS

```
C     MAIN PROGRAM
C
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPT,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
      COMMON/BETA/NRO(6,300),IB(6,300,8),NLINE(6)
      COMMON/EXTRA/ KS(20),ISW(31)
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON/NPH/ NSS(6),IFLAG(6),TITLE(6,31),SSTIME(6,31,2),ISS(6,31)
      COMMON /SEQ/INOABT(100),INHI(100),IAUP1(100),TT2(100),UP2(100)
     1,IAUP2(100)
      COMMON /TYP/EX(2,200),ISPARE(3,200),IUSED(3,200),IIUSED(3,200)
      COMMON /MAX/MAXNEQ,MAXTYP,MAXIB,MAXSTD
      COMMON /GAMMAA/XMTBA,VAR,RELGA(100),TIMA(100),XXT(200),ITT,ISEED
      COMMON /TABORT/ XTABT(1000),RDT
      COMMON /TIGAP/ UP4,XNUM,BAPRIN,AVA,XPCAP,RUNID(19),TYCOON(500)
     +,COUNTB(500),XTCUM
      COMMON /DONE/DONE(3)
C    OREILLY ADD
C DELETING THEIR PRINTOUTS WITH CHERE
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
      COMMON /KSPARE/JTIME,TOTSPR,COMB(9999),COMBA(9999),SER(100)
      COMMON /GEALG/NOSPRS
      INTEGER TOTSPR,NOSPRS,COMB,COMBA,SER
C    OREILLY STOP
      DATA  BLNK/4H    /
C
      MAXRUN=1000
      MAXNPH=6
      MAXSTD=50
      MAXNEQ=500
      MAXTYP=200
      MAXIB=300
      MAXSS=31
      MAXSEQ=100
C     CALL OVFLOW
C
```

```
C
C     OREILLY ADDS
C
C
      I=0
      NOSPRS=0
    1 I=I+1
      READ(5,9) COMB(I),COMBA(I),SER(I)
      IF(COMB(I)-1) 10,3,3
    3 IF(100-COMB(I)) 5,5,4
    4 NOSPRS=NOSPRS+1
    5 IF(100-COMBA(I)) 1,1,6
    6 NOSPRS=NOSPRS+1
      GO TO 1
    9 FORMAT(I4,I4,I4)
   10 READ (5,11) NTOTA,XFLAG,BUDGET
   11 FORMAT(I4,F4.0,F8.0)
      READ (5,13) (COST(I),I=1,NTOTA)
   13 FORMAT(F8.2)
C
      READ(5,15) JTIME,TOTSPR
   15 FORMAT (I8,I4)
C
C     OREILLY STOPS
      READ (5,19) JCC,(RUNID(I),I=1,19)
   19 FORMAT(I4,19A4)
      WRITE (6,220) JCC
      DO 1230 JC=1,JCC
   20 WRITE (6,30) (RUNID(I),I=1,19)
   30 FORMAT(1H1,30X,19A4//)
      WRITE (6,40)
      WRITE (6,50)
      WRITE (6,55)
      WRITE (6,56)
   40 FORMAT(1X,50H +++ ++++++++++++++++    TIGER   ++++++++ ++++ ++++++ )
   50 FORMAT(/1X,50H++ NAVSEC 6112 LUETJEN+MANDEL+VAIL+ALLEY+BROWN ++ )
   55 FORMAT(/1X,50H++NPS IBM/360 VERSION LT. J. LEATHER THESES 9/80++)
   56 FORMAT(/1X,50H++AS AMENDED BY LCDR. P.J. O'REILLY THESES 12/81++)
      BAPRIN=0.0
      DO 70 I=1,MAXNEQ
   60 COUNTB(I)=0.0
      TYCOON(I)=0.0
      KEQU(I)=0
   70 ETIME(I)=100000.
      NUM=0
      IPF=0
      IPR=0
      UP4=0.0
```

```
      T3=0.0
      T3SUM=0.0
      SUMX=0.0
      SUMX2=0.0
      DO 80 I=1,100
   80 TIMA(I)=0.
      DO 90 I=1,3
      DO 90 J=1,MAXTYP
   90 IIUSED(I,J)=0
      DO 100 I=1,MAXSEQ
      TT2(I)=0.0
      UP2(I)=0.0
      IAUP1(I)=0
      IAUP2(I)=0
      REDAD1(I)=0.0
      INMI(I)=0
  100 INOABT(I)=0
      IAUP=0
      XTCUM=0
      IF (JC-1) 110,110,140
  110 READ (5,120) NMAX,NOPT,PL,XK,ISEED,NPH
  120 FORMAT (2I4,2F4.0,2I4)
  130 FORMAT (1X2I6,2XF4.2,2XF5.2,2XI6,2XI4)
  140 CONTINUE
  160 WRITE (6,170) ISEED
  170 FORMAT (//1X15HRANDOM SEED IS ,I4)
      IF (NMAX-MAXRUN) 190,190,180
  180 NMAX=1000
      NOPT=1000
  190 DO 200 I=1,NMAX
  200 XTABT(I)=100000.
      WRITE (6,130) NMAX,NOPT,PL,XK,ISEED,NPH
      IF (MAXNPH-NPH) 1240,210,210
  210 INUM=50
  220 FORMAT (/1X,5HJCC= ,4I10)
  230 DO 250 I=1,191,10
      READ (5,240) XXT(I),(XXT(I+J),J=1,9)
      IF (XXT(I)) 260,260,250
  240 FORMAT (5(F2.0,F8.0))
  250 CONTINUE
  260 WRITE (6,270)
  270 FORMAT (1H1,10X40HPHASE SEQUENCE  TYPE  DURATION  CUM TIME)
      IK=1
      IK2=2*IK
      IK3=IK2-1
      IXXT=XXT(IK3)
      TIMA(1)=XXT(2)
      WRITE (6,280) IK,IXXT,XXT(IK2),TIMA(IK)
```

```
  280 FORMAT (19XI4,2XI4,2XF8.2,2XF8.2)
      DO 300 IK=2,100
      IK2=2*IK
      IK3=IK2-1
      IF (XXT(IK2)) 290,310,290
  290 TIMA(IK)=TIMA(IK-1)+XXT(IK2)
      IXXT=XXT(IK3)
      WRITE (6,280) IK,IXXT,XXT(IK2),TIMA(IK)
  300 CONTINUE
  310 CONTINUE
      IF (JC-1) 320,320,330
  320 CALL PACK
C
  330 CONTINUE
      JBB=1
      RELPY=1.0
      RELP=1.
      UP3=0.0
      TT3=0.0
      REDAD2=0.0
      DO 340 I=1,MAXSS
  340 ISW(I)=1
      ICRI=0
      DNT2=0.0
  350 STPHAS=0
      T1=0.0
C
C     RDT IS RUNNING DOWNTIME
C
      RDT=0.0
      IF (KS(8)) 380,380,360
  360 KAB=NUM+1
CHERE WRITE (6,370) KAB
  370 FORMAT(1X,16HSTART OF MISSION,I5,20H********************)
  380 KKK=0
  390 I=1
  400 LL=XXT(I)
      IF (LL) 450,450,410
  410 ENDPHA=STPHAS+XXT(I+1)
      I=I+2
      CALL RUN
      IX=NUM+1
      IF (XTABT(IX)) 420,420,440
CHERE ALSO CHANGE LABEL 420 BELOW
C 420 WRITE (6,430)
  430 FORMAT (1X44HTHE ABORT TIME IS ZERO,CHECK THE INPUT DATA.)
  420 GO TO 1240
  440 STPHAS=ENDPHA
```

```
      N=NSS(LL)+1
      GO TO 400
C
  450 NUM=NUM+1
      IF (IFFEOP) 460,460,480
  460 IFF=IFF+1
      IF (T3) 470,480,470
  470 CONTINUE
      T3SUM=T3SUM+T3
      T3=0.0
  480 XTCUM=XTCUM+XCUM
      UP4=UP4+ENDPHA-DNT2
      IF (XTABT(NUM)-100000.) 500,490,500
  490 X=ENDPHA
      GO TO 510
  500 X=XTABT(NUM)
  510 X2=X**2
      SUMX=SUMX+X
      SUMX2=SUMX2+X2
      IF (ISW(N)) 530,530,520
  520 IAUP=IAUP+1
  530 IF (NUM-INUM) 330,540,540
  540 INUM=INUM+50
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
      IF (NUM-1000.) 570,550,570
  550 WRITE (6,560) NUM
  560 FORMAT (/1X16HA GRAND TOTAL OF,I6,24H MISSIONS HAVE BEEN RUN.)
  570 XNUM=NUM
  580 XPCAP=XTCUM/XNUM
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
      IF (NUM-1000.) 610,590,610
  590 WRITE (6,600) XPCAP
  600 FORMAT (1X24HTHE RELIABILITY IS      ,F8.4)
  610 XPLCL=XPCAP-XK*SQRT(XPCAP*(1.-XPCAP)/XNUM)
      IF (XPLCL) 620,630,630
  620 XPLCL=0.0
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C    ADDRESS 631,661 ADDED FOR THIS PRINT DELETION ONLY
C    ADDRESS 630 ALSO MOVED FOR THIS DELETION
  630 IF (NUM-1000.) 661,631,661
  631 WRITE (6,640) XPLCL
C 630 WRITE (6,640) XPLCL
  640 FORMAT (1X24HTHE LOWER CONF LIMIT IS ,F8.4)
      WRITE (6,650) PL
  650 FORMAT (1X24HTHE SPEC REQUIREMENT IS ,F8.4)
      WRITE (6,660) RED2
  660 FORMAT (1X17HTHE READINESS IS ,7XF8.4)
  661 AVA=UP4/TT3
```

```
C ORBILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 669 AND 671 ADDED FOR THIS PRINT DELETION ONLY
      IF (NUM-1000.) 671,669,671
  669 WRITE (6,670) AVA
  670 FORMAT (1X28HTHE AVERAGE AVAILABILITY IS ,F8.4)
  671 XIAUP=IAUP
      AVAINS=XIAUP/XNUM
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 679 AND 681 ADDED FOR THIS PRINT DELETION ONLY
      IF (NUM-1000.) 681,679,681
  679 WRITE (6,680) AVAINS
  680 FORMAT (1X28HTHE INSTANT AVAILABILITY IS ,F8.4)
  681 XDWN=XNUM-XTCUM
      IF (XDWN) 690,690,700
  690 XMTBA=2.0*SUMX
      XLCLA=0.434*SUMX
      VAR=(0.5*SUMX)**2
      GO TO 710
  700 XMTBA=SUMX/XDWN
      VAR=(SUMX2/XNUM)-(SUMX/XNUM)**2
      CORR=(SUMX*(1/XDWN-1/XNUM))**2
      VAR=VAR+CORR
      XLCLA=XMTBA-(1.28*SQRT(VAR))
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
C ADDRESSES 741 ADDED FOR THIS PRINT DELETION ONLY
      IF (NUM-1000.) 741,710,741
  710 WRITE (6,720) XMTBA
  720 FORMAT (/1X41HTHE MEAN TIME BETWEEN MISSION FAILURES IS,F20.1)
      WRITE (6,730) XLCLA
  730 FORMAT (1X21HTHE LCL,90, MTBMF IS ,F20.1)
      WRITE (6,740) VAR
  740 FORMAT (1X27HTHE MTBMF VARIANCE IS       ,F20.1)
  741 XIFF=IFF
      XIFR=IFR
      IF (IFF) 760,750,760
  750 XMUT=2.0*UP4
      XMDT=0.0
      GO TO 790
  760 XMUT=UP4/XIFF
      IF (IFR) 780,770,780
  770 XMDT=(TT3-UP4-T3SUM)/XIFF
      GO TO 790
  780 XMDT=(TT3-UP4-T3SUM)/XIFR
C OREILLY ADD TO DELETE PRINTOUT EXCEPT FOR 1000TH MISSION.
      IF (NUM-1000.) 830,790,830
  790 WRITE (6,810) XMUT
  800 WRITE (6,820) XMDT
  810 FORMAT (/1X18HTHE SYSTEM MUT IS ,F20.1)
```

```
 820 FORMAT (1X18HTHE SYSTEM MDT IS ,F20.3)
 830 IF (XPCAP-PL) 840,840,920
 840 IF (NOPT-NUM) 870,870,850
 850 WRITE (6,860)
 860 FORMAT (1X14HANOTHER SET OF,3H 50,20HMISSIONS WILL BE RUN,43H TO O
    1BTAIN REQUIRED STATISTICAL CONFIDENCE.)
     GO TO 330
 870 WRITE (6,880)
 880 FORMAT (1X52HSIMULATION COMPLETE-OPTIMUM NUMBER MISSIONS WERE RUN)
     IF(PL.EQ.1.) GO TO 910
 890 WRITE (6,900)
 900 FORMAT (1X33HWEAPON SYSTEM FAILS REQUIREMENTS.)
 910 GO TO 1010
 920 IF (NMAX-NUM) 930,930,960
 930 WRITE (6,940)
 940 FORMAT (1X52HSIM COMPLETE-PREDEFINED MAX NUMBER MISSIONS WERE RUN)
 950 IF (XPLCL-PL) 890,990,990
 960 IF (XPLCL-PL) 850,970,970
 970 WRITE (6,980)
 980 FORMAT (2X22HSIMULATION COMPLETE - )
     IF(PL.EQ.1.) GO TO 1010
 990 WRITE (6,1000)
1000 FORMAT (1X33HWEAPON SYSTEM MEETS REQUIREMENTS.)
1010 CONTINUE
     IF (JC-1) 1020,1020,1040
1020 READ (5,1030) SPRS,APPL,GMMA,DMNO
1030 FORMAT (4A4)
1040 IF (SPRS.EQ.BLNK) GO TO 1190
1050 IDIFF=0
     TAFM=0.0
     TACMMH=0.0
     WRITE (6,1060)
1060 FORMAT (1H1,4X53HEQUIP FAILURES AND CORRECTIVE MAINTENANCE(CM) SUM
    1MARY/8X71HEQUIP. NO.  TYPE NO.  TOTAL EQUIP.  AVG. NO. FAILURES  A
   2VG. CM MANHOURS/32X8HFAILURES,7X11HPER MISSION,5X11HPER MISSION/)
     DO 1090 I=1,NEQ
     IF(XMTTR(IEQU(I)).EQ.9999.) GO TO 1090
     IF (KEQU(I)) 1090,1090,1070
1070 AFM=KEQU(I)/XNUM
     IEQ=IABS(IEQU(I))
     ACMMH=AFM*ABS(XMTTR(IEQ))
     WRITE(6,1080) I,IEQ,KEQU(I),AFM,ACMMH
1080 FORMAT (10XI4,6XI4,6XI10,6XF10.3,6XF10.3)
     IDIFF=IDIFF+KEQU(I)
     TAFM=TAFM+AFM
     TACMMH=TACMMH+ACMMH
1090 CONTINUE
     WRITE (6,1100) IDIFF,TAFM,TACMMH
```

```
1100 FORMAT (31X10H----------,6X10H----------,6X10H----------/31XI10,6X
    1F10.3,6XF10.3)
1110 CONTINUE
     WRITE (6,1120)
1120 FORMAT (1H1,3X41HAVERAGE NUMBER OF SPARES USED PER MISSION)
     WRITE (6,1130)
1130 FORMAT (/4X6HSPARES,7X4HSHIP,18X6HTENDER,16X4HBASE)
     WRITE (6,1140)
1140 FORMAT (8X4HTYPE,4X3(5HSTOCK,3X4HUSED,10X))
     DO 1170 J=1,NTYPE
     ALDONE=0.0
     DO 1150 I=1,3
     DONE(I)=IIUSED(I,J)/XNUM
     ALDONE=ALDONE+DONE(I)
1150 CONTINUE
     IF(ALDONE) 1155,1170,1155
1155 WRITE(6,1160)J,(ISPARE(I,J),DONE(I),I=1,3)
1160 FORMAT (8XI4,4X3(I5,F7.2,10X))
1170 CONTINUE
1180 CONTINUE
1190 IF (APPL.EQ.BLNK) GO TO 1210
1200 BAPRIN=-1.0
     CALL APPLE
1210 CONTINUE
1220 CONTINUE
1230 CONTINUE
1240 STOP
     END
C
C
C
C
     SUBROUTINE RUN
     COMMON /MAX/MAXNEQ,MAXTYP,MAXIB,MAXSTD
     COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
    1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
    2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
     COMMON/BETA/NRO(6,300),IB(6,300,8),NLINE(6)
     COMMON/EXTRA/ KS(20),ISW(31)
     COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
     COMMON/NPH/ NSS(6),IFLAG(6),TITLE(6,31),SSTIME(6,31,2),ISS(6,31)
     COMMON /SEQ/INOABT(100),INMI(100),IAUP1(100),TT2(100),UP2(100)
    1,IAUP2(100)
     COMMON /TYP/EX(2,200),ISPARE(3,200),IUSED(3,200),IIUSED(3,200)
     COMMON /GAMMAA/XMTBA,VAR,RELGA(100),TIMA(100),XXT(200),ITT,ISEED
     COMMON /TABORT/ XTABT(1000),RDT
     COMMON /DELTA/KKK2
     COMMON /XXX/XXX
```

```
      COMMON/VDC/VDC(50,6),IUI(200),VMTTR(200,6),TAD2
      COMMON/STAN/ISTB(60,10,6)
      COMMON/RUNAP/ITEMP2,DELT,ISSA(31),ISSC
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
C
      TDEOP=0.0
      TP=STPHAS
      KAA=NUM+1
      XKAA=KAA
      NX=NSS(LL)
      N=NX+1
      ITEMP=0
      ITEMP2=0
      IF (KKK) 40,10,40
   10 DO 20 I=1,3
      DO 20 J=1,NTYPE
      IUSED(I,J)=0
   20 CONTINUE
      DO 30 I=1,NEQ
   30 ETIME(I)=100000.
   40 CONTINUE
C
   50 DO 120 ILB=1,NEQ
      KEQ=ILB
      IF(ETIME(KEQ)+100001.001)55,120,55
   55 IF(ETIME(KEQ)+99999.)60,60,120
   60 IF (IFLAG(LL)) 120,70,120
C
   70 ETIME(KEQ)=STPHAS
      IABC=IABS(IEQU(KEQ))
      IF (XMTTR(IABC)) 80,80,100
   80 XXX=VMTTR(IABC,LL)
      IF (XXX-9999.) 120,90,120
   90 ETIME(KEQ)=-99999.
      GO TO 120
  100 XXX=XMTTR(IABC)
  110 CALL TTE
  120 CONTINUE
C
      DO 140 ILB=1,NEQ
      KEQ=ILB
      IEQU(KEQ)=IABS(IEQU(KEQ))
      IF (ETIME(KEQ)-100000.) 130,140,130
  130 IEQU(KEQ)=-IABS(IEQU(KEQ))
  140 CONTINUE
  150 CONTINUE
C
      KKK2=KKK
```

```
      K=NLINE(LL)
      DO 250 I=1,K
      DO 250 J=2,8
      KEQ=IABS(IB(LL,I,J))
      IF (KEQ-MAXNEQ) 151,151,250
  151 IF(KEQ) 250,250,155
  155 IF(ETIME(KEQ)+100001.001) 160,250,160
  160 IEQU(KEQ)=IABS(IEQU(KEQ))
      IABC=IEQU(KEQ)
      IF (XMTTR(IABC)) 170,170,180
  170 IF (VMTTR(IABC,LL)-9999.) 180,190,180
  180 CONTINUE
      IF (IFLAG(LL)-1) 210,190,210
  190 IF (ETIME(KEQ)) 200,210,210
  200 ETIME(KEQ)=ETIME(KEQ)-(ENDPHA-STPHAS)
  210 IF (ETIME(KEQ)-100000.) 220,240,220
  220 IF (ABS(ETIME(KEQ))-STPHAS) 240,230,230
  230 IF (STPHAS) 250,240,250
  240 ETIME(KEQ)=-STPHAS
      IABC=IABS(IEQU(KEQ))
      XXX=XMTBF(IABC)
      CALL TTE
  250 CONTINUE
      KKK2=1
C
      DO 330 ILB=1,NEQ
      KEQ=ILB
      IF(ETIME(KEQ)+100001.001) 255,330,255
  255 IF(IEQU(KEQ)) 260,260,330
  260 IEQU(KEQ)=IABS(IEQU(KEQ))
      IABC=IEQU(KEQ)
      IF (XMTTR(IABC)) 270,270,280
  270 IF (VMTTR(IABC,LL)-9999.) 280,290,280
  280 CONTINUE
      IF (IFLAG(LL)-1) 310,290,310
  290 IF (ETIME(KEQ)) 300,320,320
  300 ETIME(KEQ)=ETIME(KEQ)-(ENDPHA-STPHAS)
      GO TO 330
C
  310 IF(ETIME(KEQ)) 331,320,320
  320 ETIME(KEQ)=100000.
      IEQU(KEQ)=IABS(IEQU(KEQ))
      GO TO 330
  331 IEQU(KEQ)=-IABS(IEQU(KEQ))
  330 CONTINUE
C
      CALL STATUS
      CALL STNDBY
```

```
C
      CALL STATUS
      IF (ISW(N)) 350,350,340
  340 IAUP1(JBB)=IAUP1(JBB)+1
  350 XIAUPI=IAUP1(JBB)
      XAVI=XIAUPI/XKAA
C
      TIME=STPHAS
      DNT1=0.0
      DO 360 KSS=1,N
  360 SSTIME(LL,KSS,1)=0.0
C
  370 TP=TIME
      CALL STNDBY
  380 IF (KS(6)) 390,440,390
  390 WRITE (6,430) TP
      DO 410 J=1,NEQ
      IF (ETIME(J)-100000.) 400,410,400
  400 IEQ=IABS(IEQU(J))
      WRITE(6,420) J,IEQ,ETIME(J)
  410 CONTINUE
  420 FORMAT (1XI5,1XI5,5XF22.4)
  430 FORMAT (1XF12.4)
  440 CALL EVENT
      TIME=ABS(ETIME(KEQ))
      IF (KS(5)) 450,470,450
  450 WRITE (6,460) KEQ,ETIME(KEQ),KAA
  460 FORMAT (10X5HEQUIP,I5,F12.4,5X7HMISSION,I10)
  470 DELT=TIME-TP
      CALL STATUS
C
  480 DO 510 KSS=1,NX
      IF (ISW(KSS)) 490,490,500
  490 SSTIME(LL,KSS,1)=SSTIME(LL,KSS,1)+DELT
      GO TO 510
  500 SSTIME(LL,KSS,1)=0.0
  510 CONTINUE
      IF (ISW(N)) 520,520,530
  520 SSTIME(LL,N,1)=SSTIME(LL,N,1)+DELT
      T3=T3+DELT
      IF (TIME-ENDPHA) 522,522,521
  521 T3=T3+ENDPHA-TP-DELT
  522 RDT=RDT+DELT
      GO TO 550
  530 T3=0.0
      RDT=0.0
      IF (SSTIME(LL,N,1)) 1140,550,540
  540 T1=SSTIME(LL,N,1)
```

```
      SSTIME(LL,N,1)=0.0
  550 CONTINUE
C
      IF (SSTIME(LL,N,1)) 570,560,570
  560 IF (T1) 620,620,580
  570 IF (T1) 620,610,620
  580 IPF=IPF+1
  590 IPR=IPR+1
  600 T1=0.0
      GO TO 620
  610 T1=SSTIME(LL,N,1)
  620 CONTINUE
C
      IF(ICRI) 640,640,660
C
  640 ISSC=1
      ISSA(1)=N
      IF(RDT-TAD2) 645,645,930
  645 ICRI=0
      IF(SSTIME(LL,N,1) -SSTIME(LL,N,2)) 650,650,960
  650 ICRI=0
      ISSC=0
      DO 655 KSS=1,NX
      IF(SSTIME(LL,KSS,1)-SSTIME(LL,KSS,2))655,655,652
  652 ISSC=ISSC+1
      ISSA(ISSC)=KSS
  655 CONTINUE
      IF(ISSC) 660,660,962
  660 CONTINUE
C
      IF (TIME-ENDPHA) 670,670,1140
  670 IF (ISW(N)) 680,680,730
  680 CALL APPLE
  730 IF (ETIME(KEQ)) 810,810,740
  740 IABC=IABS(IEQU(KEQ))
      IF (IFLAG(LL)-1) 750,760,750
  750 CALL LRND(ISEED,RN,1,16807,0)
      IF (RN-REPOL) 770,770,800
  760 ETIME(KEQ)=-99999.
      GO TO 830
  770 IF (XMTTR(IABC)) 780,780,790
  780 XXX=VMTTR(IABC,LL)
      IF (XXX-9999.) 820,760,820
  790 XXX=XMTTR(IABC)
      GO TO 820
  800 ETIME(KEQ)=-100001.001
      GO TO 830
  810 IABC=IABS(IEQU(KEQ))
```

```
      XXX=XMTBF(IABC)
  820 IF(IEQU(KEQ))811,821,821
  811 IEQU(KEQ)=IABS(IEQU(KEQ))
      ETIME(KEQ)=100000.
      GO TO 830
  821 CALL TTE
  830 IF (ETIME(KEQ)) 840,1150,870
C
  840 KEQU(KEQ)=KEQU(KEQ)+1
      IF (ISW(N)) 850,850,370
  850 DNT1=DNT1+DELT
      IF (ICRI) 860,370,860
  860 REDAD1(JBB)=REDAD1(JBB)+DELT
      GO TO 370
C
  870 CONTINUE
      IF (ISW(N)) 880,880,370
  880 DNT1=DNT1+DELT
      IF (ICRI) 890,900,890
  890 REDAD1(JBB)=REDAD1(JBB)+DELT
  900 TDOWN=TIME-SSTIME(LL,N,1)
      TTEMP=SSTIME(LL,N,1)
      IF (KS(13)) 370,370,910
CHERE ALSO CHANGE LABEL 910
C 910 WRITE (6,920) LL,TDOWN,TTEMP,KAA
  920 FORMAT (13H DURING PHASE,I6,20HSYSTEM WENT DOWN AT ,F14.4,13H DOWN
     1TIME IS ,F14.4,3X7HMISSION,I6)
  910 GO TO 370
C
  930 ICRI=5
      TABORT=TIME-(RDT-TAD2)
      IF(TABORT-ENDPHA) 940,645,645
  940 IF (XTABT(KAA)-100000.) 660,950,660
  950 ITEMP=1
      ITEMP2=1
CHERE WRITE(6,1010)LL,JBB,KAA,TABORT,TITLE(LL,N),TAD2
      GO TO 1020
  960 ICRI=4
      GO TO 964
  962 ICRI=2
  964 TABORT=TIME-(SSTIME(LL,ISSA(1),1)-SSTIME(LL,ISSA(1),2))
  970 IF (TABORT-ENDPHA) 990,980,980
  980 IF(ICRI-2)650,985,650
  985 ICRI=0
      GO TO 660
  990 IF (XTABT(KAA)-100000.) 660,1000,660
 1000 ITEMP=1
      ITEMP2=1
```

```
CHERE DO 1005 I=1,ISSC
C1005 WRITE(6,1009)LL,JBB,KAA,TABORT,TITLE(LL,ISSA(I))
C     1,SSTIME(LL,ISSA(I),2)
 1009 FORMAT(1X9HIN PHASE ,I2,1X3HSEQ,I3,4X7HMISSION,I6,4X15HABORTED AT
     1TIME,F10.4,10H  BECAUSE ,A4,35H  EXCEEDED PHASE ALLOWABLE DOWNTIME
     2,2XF10.3,5H HRS.)
 1010 FORMAT (1X9HIN PHASE ,I2,1X3HSEQ,I3,4X7HMISSION,I6,4X15HABORTED AT
     1 TIME,F10.4,10H  BECAUSE ,A4,37H  EXCEEDED MISSION ALLOWABLE DOWNT
     2IME,2XF10.3,5H HRS.)
 1020 XTABT(KAA)=TABORT
      IF (TABORT) 1590,1590,1040
 1040 DO 1110 I=1,NEQ
      IF (ETIME(I)) 1050,1110,1110
 1050 IF (IEQU(I)) 1080,1110,1080
 1080 IF (KS(2)) 1110,1110,1110
CHERE PREVIOUS LINE WAS 1090,1110,1090
C1090 WRITE (6,1100) I,ETIME(I)
 1100 FORMAT (17X9HEQUIPMENT,I5,24H DOWN IT WILL COME UP AT,F16.4)
 1110 CONTINUE
 1120 CALL APPLE
      ITEMP2=0
 1130 GO TO 660
C
 1140 CONTINUE
      IFFEOP=ISW(N)
      IF (ISW(N)) 1160,1160,1270
 1150 CONTINUE
 1160 TDEOP=ENDPHA-TP
 1170 CONTINUE
      IF (KS(3)) 1210,1210,1180
 1180 IF (TDEOP) 1210,1210,1210
CHERE PREVIOUS LINE WAS 1190,1210,1190
C1190 WRITE (6,1200) LL,TDEOP,KAA
 1200 FORMAT (1X27HSYSTEM DOWN AT END OF PHASE,I6,13H FOR DURATION,F10.4
     1,6X7HMISSION,I6)
 1210 CONTINUE
      DNT1=DNT1+TDEOP
      RDT=RDT+TDEOP-DELT
      DELT=TDEOP
      CALL APPLE
 1270 CONTINUE
      IF (ICRI) 1280,1290,1280
 1280 REDAD1(JBB)=REDAD1(JBB)+TDEOP
 1290 DNT2=DNT2+DNT1
 1300 IF (DNT2) 1310,1330,1310
 1310 IF(KS(6)) 1330,1330,1330
CHERE PREVIOUS LINE WAS 1325,1330,1325
C1325 WRITE(6,1320) LL,KAA,DNT2
```

```
 1320 FORMAT (1X5HPHASE,I5,1X29HTOTAL SYS DOWNTIME IN MISSION,I5,1X3HWAS
     1,F12.4,4H HRS)
 1330 CONTINUE
C
      IF (ICRI) 1350,1350,1340
 1340 IF (ITEMP) 1360,1360,1350
 1350 XCUM=1-ITEMP
      INOABT(JBB)=INOABT(JBB)+1-ITEMP
      INMI(JBB)=INMI(JBB)+1
 1360 CONTINUE
      XNO=INOABT(JBB)
      TNMI=INMI(JBB)
      IF (TNMI) 1380,1380,1370
 1370 RELY=XNO/TNMI
      GO TO 1390
 1380 RELY=0.0
 1390 RELPY=RELPY*RELY
      TT1=ENDPHA-STPHAS
      TT2(JBB)=TT2(JBB)+TT1
      UP1=TT1-DNT1
      UP2(JBB)=UP2(JBB)+UP1
      IF (ISW(N)) 1410,1410,1400
 1400 IAUP2(JBB)=IAUP2(JBB)+1
 1410  XIAUPP=IAUP2(JBB)
      XAV=XIAUPP/XKAA
      IF (KAA-INUM) 1570,1420,1570
CHERE1
C1420 WRITE (6,1430) XAVI
 1430 FORMAT (/47X20HINSTANT AVAILABILITY,5X2X4H IS ,F6.4)
CHERE1
C1440 WRITE (6,1450) LL,JBB,RELY,LL,RELPY
 1450 FORMAT (9X17HRELIABILITY PHASE,I3,1H,,I3,5H, IS ,F6.4,3X25HRELIABI
     1LITY UP TO PHASE  ,I2,4H IS ,F6.4)
CHERE 1420 IN BELOW LINE SHOULD BE NEXT TO ABOVE WRITE(6,1430)
 1420 RELGA(JBB)=RELPY
      AENDT1=0.0
      AENDT2=0.0
      DO 1520 I=1,KAA
 1460 IF (XTABT(I)-100000.) 1470,1520,1520
 1470 IF (XTABT(I)-TIMA(JBB)) 1480,1520,1520
 1480 AENDT2=AENDT2+TIMA(JBB)-XTABT(I)
      JBB1=JBB-1
      IF (JBB1) 1500,1500,1490
 1490 IF (TIMA(JBB1)-XTABT(I)) 1500,1500,1510
 1500 AENDT1=AENDT1+TIMA(JBB)-XTABT(I)
      GO TO 1520
 1510 AENDT1=AENDT1+TIMA(JBB)-TIMA(JBB1)
 1520 CONTINUE
```

```
      TT3=TT3+TT2(JBB)
      UP3=UP3+UP2(JBB)
      REDAD2=REDAD2+REDAD1(JBB)
      RED1=(UP2(JBB)-AENDT1+REDAD1(JBB))/TT2(JBB)
      RED2=(UP3-AENDT2+REDAD2)/TT3
CHERE 1530 LABEL TRANSFERRED BELOW
C1530 WRITE (6,1540) RED1,RED2
 1540 FORMAT (9X16HREADINESS          ,9X4H IS ,F6.4,3X25HREADINESS
     1         ,2X4H IS ,F6.4)
 1530 AVA1=UP2(JBB)/TT2(JBB)
      AVA2=UP3/TT3
CHERE WRITE (6,1550) AVA1,AVA2
 1550 FORMAT (9X23HAVERAGE AVAILABILITY    ,2X4H IS ,F6.4,3X25HAVERAGE AV
     1AILABILITY       ,2X4H IS ,F6.4)
CHERE WRITE (6,1560) XAV
 1560 FORMAT (47X20HINSTANT AVAILABILITY,5X2X4H IS ,F6.4)
 1570 CONTINUE
 1580 KKK=1
      JBB=JBB+1
      T1=SSTIME(LL,N,1)
 1590 RETURN
      END
C
C
C
      SUBROUTINE PACK
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFPEOP,T3,TIME,T3SUM
      COMMON/BETA/NRO(6,300),IB(6,300,8),NLINE(6)
      COMMON/EXTRA/ KS(20),ISW(31)
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON/NPH/ NSS(6),IFLAG(6),TITLE(6,31),SSTIME(6,31,2),ISS(6,31)
      COMMON /TYP/EX(2,200),ISPARE(3,200),IUSED(3,200),IIUSED(3,200)
      COMMON /MAX/MAXNEQ,MAXTYP,MAXIB,MAXSTD
      COMMON/VDC/VDC(50,6),IUI(200),VMTTR(200,6),TAD2
      COMMON /PACKAP/ IBNUM( 6,500),ISYS( 6),F(200,4)
      COMMON/STAN/ISTB(60,10,6)
      COMMON /CSPARE/ SPR1,SPR2,SPR3,SPR4,SPR5,SPR6,SPR7,SPR8,SPR9
     1,SPR10,SPR11,SPR12,SPR13,SPR14,ITMPOP(200)
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
      DIMENSION LOAD(19)
      DIMENSION DUM(4)
      DIMENSION IVAL(10)
      DATA IBLANK/4H    /
C
      READ (5,10) KOPT,(KS(I),I=1,13)
      WRITE (6,20) KOPT,(KS(I),I=1,13)
```

```
   10 FORMAT  (20I4)
   20 FORMAT  (1H1,I10,5X19I4)
C
      READ  (5,10)  (IFLAG(I),I=1,NPH)
      WRITE  (6,30)  (IFLAG(I),I=1,NPH)
   30 FORMAT  (10I4)
C
      READ(5,40)  REPOL,TAD2,XM,XM1
   40 FORMAT(F4.0,F8.0, 2F4.0)
   50 FORMAT(20F4.0)
      IF(XM)  35,35,55
   35 XM=1.0
   55 IF(XM1)  36,36,56
   36 XM1=1.
   56 WRITE(6,60)  REPOL,TAD2,XM,XM1
   60 FORMAT(1X,4F10.2)
      GO TO  (70,90,100, 120, 130),KOPT
C
   70 KS(1)=1
      KS(4)=0
   80 KS(3)=0
      KS(2)=0
      KS(2)=1
      KS(5)=0
      KS(6)=0
      KS(7)=0
      KS(8)=0
      KS(9)=0
      KS(10)=0
      GO TO 130
   90 KS(1)=1
      KS(6)=0
      KS(10)=0
      GO TO 110
  100 KS(1)=1
      KS(6)=1
      KS(7)=1
      KS(10)=1
      KS(12)=1
  110 KS(2)=1
      KS(3)=1
      KS(4)=1
      KS(5)=1
      KS(7)=0
      KS(8)=1
      KS(9)=1
      GO TO 130
  120 KS(1)=0
```

```
      KS(4)=0
      GO TO 80
C
  130 NEQ=0
      DO 140 I=1,MAXNEQ
      ETIME(I)=100000.
      IEQU(I)=0
  140 CONTINUE
      DO 155 J=1,6
      DO 150 I=1,MAXTYP
      XMTBF(I)=0.0
      VMTTR(I,J)=0.0
  150 XMTTR(I)=0.0
  155 CONTINUE
C
  160 WRITE (6,170)
  170 FORMAT (/11H TYPE   NAME,18X4HMTBF,5X4HMTTR,7X2HDC,8X4HADT1,4X4HADT
     12)
  180 READ (5,190) I,(DUM(J),J=1,4),X,Y,U,V,W,IDUM
  190 FORMAT (I4,4A4,F8.0,4F4.0,I4)
      IF (I) 200,490,200
  200 IF (I-MAXTYP) 220,220,210
  210 WRITE (6,440)
      GO TO 1000
  220 DO 230 J=1,4
  230 F(I,J)=DUM(J)
      IUI(I)=IDUM
      IF (IUI(I)) 240,250,240
  240 READ (5,450) IU,(VDC(IU,ILL),ILL=1,NPH)
  250 IF (Y) 260,280,280
  260 READ (5,50) (VMTTR(I,J),J=1,NPH)
  270 IF (I) 280,490,280
  280 EX(1,I)=V
      EX(2,I)=W
      IF (KS(1)) 310,310,290
  290 WRITE (6,300) I,(F(I,J),J=1,4),X,Y,U,V,W
  300 FORMAT (1XI4,2X4A4,2XF10.1,F10.2,F10.3,2(F8.1))
  310 IF (IUI(I)) 380,380,320
  320 IF (KS(1)) 340,340,330
  330 WRITE (6,460) (VDC(IU,ILL),ILL=1,NPH)
  340 DO 370 ILL=1,NPH
      IF (VDC(IU,ILL)) 360,360,350
  350 VDC(IU,ILL)=(X/VDC(IU,ILL))*XM
      GO TO 370
  360 VDC(IU,ILL)=(X/.0001)*XM
  370 CONTINUE
  380 IF (KS(1)) 410,410,390
  390 IF (Y) 400,410,410
```

```
  400 WRITE (6,470) (VMTTR(I,J),J=1,NPH)
  410 IF (XMTBF(I)) 420,430,420
  420 WRITE (6,480) I
      GO TO 1000
  430 IF(U) 435,435,433
  433 XMTBF(I)=XM*(X/U)
  435 XMTTR(I)=Y*XM1
      GO TO 180
  440 FORMAT (9X39HEQUIP TYPES HAVE EXCEEDED MAX ALLOWABLE)
  450 FORMAT (I4,19(F4.0))
  460 FORMAT (14X16HVARY DUTY CYCLE ,4F10.3)
  470 FORMAT (14X16HVARIABLE MTTR    ,4F10.3)
  480 FORMAT (1X4HTYPE,I5,1X13HDEFINED TWICE)
C
  490 WRITE (6,500)
  500 FORMAT (/1X15HTYPE  EQUIPMENT)
  510 READ (5,10) NTYPE,(LOAD(I),I=1,19)
      IF (LOAD(1)) 520,650,520
  520 DO 620 I=1,19
      IF (LOAD(I)) 530,620,530
  530 IBM=LOAD(I)
      IF (IBM-500) 560,560,540
  540 WRITE (6,550)
  550 FORMAT(1X,'EQUIPMENT NUMBER GREATER THAN 500 ******************')
      GO TO 1000
  560 IF (IBM-NEQ) 580,580,570
  570 NEQ=IBM
  580 IF (IEQU(IBM)) 590,610,590
  590 WRITE (6,600) IBM
      GO TO 1000
  600 FORMAT (1X9HEQUIPMENT,I5,1X34HDEFINED TWICE ********************)
  610 CONTINUE
      IEQU(IBM)=NTYPE
  620 CONTINUE

      IF (KS(1)) 640,640,630
  630 WRITE (6,10) NTYPE,(LOAD(I),I=1,19)
  640 NTY=NTYPE
      GO TO 510
C
C OREILLY CHANGE
C 650 WRITE (6,660)
C 660 FORMAT(/1X11HSPARES TYPE,6X4HSHIP,4X6HTENDER,6X4HBASE,12X6HFACTOR)
  650 DO 670 I=1,3
C OREILLY CHANGE - END
      NTYPE=NTY
      DO 670 J=1,NTYPE
  670 IUSED(I,J)=0
```

```
      READ(5,675) IUNLIM,SX,SPR1,SPR2,SPR3,SPR4,SPR5,SPR6,SPR7,SPR8,SPR9
     1,SPR10,SPR11,SPR12,SPR13,SPR14
  675 FORMAT(A4,16X,15F4.0)
      IF(SX-999.) 681,676,681
  676 CALL SPARES
      IF(KS(1)) 740,740,677
  677 DO 678 I=1,NTYPE
  678 WRITE(6,750) I,(ISPARE(J,I),J=1,3),SX
      GO TO 740
  681 IF(SX) 684,682,684
  682 SX=1.0
  684 IF(IUNLIM-IBLANK) 690,720,690
  690 WRITE (6,700)
  700 FORMAT (1X41HALL  EQUIPMENT TYPES HAVE UNLIMITED SPARES)
      DO 710 I=1,NTYPE
      DO 710 J=1,3
  710 ISPARE(J,I)=90000
      GO TO 760
  720 DO 740 I=1,NTYPE
      READ (5,10)  (ISPARE(J,I),J=1,3)
      BILL=FLOAT(ISPARE(1,I))*SX
      IF(INT(BILL)-BILL)  727,725,727
  725 ISPARE(1,I)=BILL
      GO TO 728
  727 ISPARE(1,I)=INT(BILL)+1
  728 CONTINUE
      IF  (KS(1))  740,740,730
  730 WRITE(6,750)I,(ISPARE(J,I),J=1,3),SX
  740 CONTINUE
  750 FORMAT(5X,I4,2X,3I10,13X,F6.2)
C
  760 WRITE (6,770)  NPH
  770 FORMAT (1H1,3X28HTHE MISSION WILL BE RUN WITH,I4,7H  PHASE ,27HTYPE
     1S IN VARIABLE SEQUENCE.)
C
      DO 777 I=1,6
      DO 776 J=1,10
      DO 775 K=1,60
      ISTB(K,J,I)=0
  775 CONTINUE
  776 CONTINUE
  777 CONTINUE
      DO 990 K=1,NPH
      READ (5,780) XID,LL,NSS(K),ISS(K,NSS(K)+1),SSTIME(K,NSS(K)+1,2)
      ISYS(K)=ISS(K,NSS(K)+1)
  780 FORMAT (A4,3I4,F8.0)
      NX=NSS(K)
      N=NX+1
```

```
      IF (KS(1)) 820,820,790
  790 WRITE (6,810) XID,LL,NSS(K),ISS(K,N),SSTIME(K,N,2)
  800 FORMAT (1XA4,3I4,F10.2)
  810 FORMAT (/1XA4,3I4,F10.2)
  820 TITLE(K,N)=XID
      DO 840 IK=1,NX
      READ (5,780) TITLE(K,IK),KK,MM,ISS(K,IK),SSTIME(K,IK,2)
      IF (KS(1)) 840,840,830
  830 WRITE (6,800) TITLE(K,IK),LL,MM,ISS(K,IK),SSTIME(K,IK,2)
  840 CONTINUE
C
      DO 850 JA=1,MAXIB
      DO 850 JB=1,8
      IB(K,JA,JB)=0
      NRO(K,JA)=0
  850 CONTINUE
      IOR=0
      I=0
  860 I=I+1
      READ(5,10) (IVAL(J),J=1,10),IRULE
      IF(IVAL(1).EQ.0) GO TO 990
      IF(IRULE.NE.0) GOTO 930
C
      IF(I.LE.MAXIB) GO TO 880
      WRITE(6,870) MAXIB
  870 FORMAT(1H1,10X,29H# OF GROUP CARDS GREATER THAN,I4)
      STOP
  880 NRO(K,I)=IVAL(1)
      DO 890 J=1,8
      IB(K,I,J)=IVAL(J+1)
  890 CONTINUE
      IBNUM(K,IB(K,I,1)-500)=I
      NLINE(K)=I
  900 IF(KS(1)) 860,860,910
  910 WRITE(6,920) NRO(K,I),(IB(K,I,J),J=1,8)
  920 FORMAT(1X,I3,8I4)
      GO TO 860
  930 CONTINUE
      I=I-1
      IOR=IOR+1
C
      IF(IOR.LE.MAXSTD) GO TO 950
      WRITE(6,940) MAXSTD
  940 FORMAT(1H1,10X,36H# OF OPERATE RULE CARDS GREATER THAN,I4)
      STOP
  950 CONTINUE
      DO 960 J=1,10
      ISTB(IOR,J,K)=IVAL(J)
```

```
  960 CONTINUE
      IF(KS(1)) 860,860,970
  970 WRITE(6,980) (ISTB(IOR,J,K),J=1,10)
  980 FORMAT(30X,10I4)
      GO TO 860
  990 CONTINUE
 1000 CONTINUE
      RETURN
      END
C
C
C
C
      SUBROUTINE EVENT
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NOM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IPFEOP,T3,TIME,T3SUM
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
C
      R=ABS(ETIME(1))
      KEQ=1
      DO 20 I=2,NEQ
      RR=ABS(ETIME(I))
      IF (R-RR) 20,20,10
   10 R=RR
      KEQ=I
   20 CONTINUE
      RETURN
      END
C
C
C
      SUBROUTINE TTE
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NOM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IPFEOP,T3,TIME,T3SUM
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON/EXTRA/ KS(20),ISW(31)
      COMMON/NPH/ NSS(6),IFLAG(6),TITLE(6,31),SSTIME(6,31,2),ISS(6,31)
      COMMON /TYP/EX(2,200),ISPARE(3,200),IUSED(3,200),IIUSED(3,200)
      COMMON /DELTA/KKK2
      COMMON /XXX/XXX
      COMMON/VDC/VDC(50,6),IUI(200),VMTTR(200,6),TAD2
      COMMON /GAMMAA/XMTBA,VAR,RELGA(100),TIMA(100),XXT(200),ITT,ISEED
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
C
   10 K=KEQ
```

```
   20 J=IABS(IEQU(K))
      IF (ETIME(K)-100000.) 30,120,30
   30 IF (ETIME(K)) 120,120,40
C
   40 IF (ABS(XXX)-9999.) 41,120,41
   41 DO 60 I=1,2
      IF (ISPARE(I,J)-IUSED(I,J)) 60,60,50
   50 IUSED(I,J)=IUSED(I,J)+1
      IIUSED(I,J)=IIUSED(I,J)+1
      II=I
      GO TO 120
   60 CONTINUE
      IF (ISPARE(3,J)-IUSED(3,J)) 70,70,110
   70 IF (ETIME(K)-100000.) 80,120,80
   80 ETIME(K)=-500000.
      IF (KS(12)) 340,340,90
   90 WRITE (6,100) J
  100 FORMAT (1X15HEQUIPMENT TYPE ,I4,25H HAS CONSUMED ALL SPARES.)
      GO TO 340
  110 IUSED(3,J)=IUSED(3,J)+1
      IIUSED(3,J)=IIUSED(3,J)+1
      II=3
C
  120 XXX=ABS(XXX)
C
      IF (KKK2) 140,130,140
  130 TP=0
      II=0
  140 IF (ETIME(K)-100000.) 160,150,160
  150 ETIME(K)=-TP
      GO TO 170
  160 IF (ETIME(K)) 170,170,180
  170 X=1.
      GO TO 190
  180 X=-1.
  190 CALL LRND(ISEED,RN,1,16807,0)
      IF (II-2) 200,210,210
  200 ADT=0.
      GO TO 220
  210 III=II-1
      ADT=EX(III,J)
  220 CONTINUE
      IF (ETIME(K)) 230,230,330
  230 K1=IABS(IEQU(K))
      IF (IUI(K1)) 330,330,240
  240 IU=IUI(K1)
      ST=0.0
      SR=1.0
```

```
      RN3=RN
      DO 310 I=JBB,100
      T=XXT(2*I)
      IF (T) 250,320,250
  250 IF (ST) 300,260,300
  260 T=TIMA(I)+ETIME(K)
      IF (T) 270,310,300
  270 T=0
      GO TO 310
  300 LLL=XXT(2*I-1)
      XM=VDC(IU,LLL)
      IF (XM) 280,320,280
  280 R=EXP(-T/XM)
      SR=SR*R
      IF (SR-RN) 320,320,290
  290 ST=ST+T
      RN3=RN/SR
  310 CONTINUE
  320 ETIME(K)=ST-(XM*ALOG(RN3))+ABS(ETIME(K))+ADT
      GO TO 340
  330 ETIME(K)=X*(-XXX*ALOG(RN)+ABS(ETIME(K))+ADT)
  340 IF (IFLAG(LL)-1) 370,370,350
  350 IF (ETIME(K)+500000.) 360,370,360
  360 ETIME(K)=100000.
  370 CONTINUE
      RETURN
      END
C
C
C
C
C
C
C
      SUBROUTINE STNDBY
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NOM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON /XXX/XXX
      COMMON/STAN/ISTB(60,10,6)
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
      DO 170 I=1,50
      IF (ISTB(I,1,LL)) 10,180,10
C
   10 INDEX=1
      DO 50 J=2,10
      KK=ISTB(I,J,LL)
```

```
      IF (KK) 30,60,20
   20 IF (ETIME(KK)) 40,50,50
C
   30 KK=IABS(KK)
      IF (ETIME(KK)) 40,40,50
   40 INDEX=0
      GO TO 60
   50 CONTINUE
C
   60 K=IABS(ISTB(I,1,LL))
C
      ISO=ISTB(I,1,LL)
C
   70 IF (ETIME(K)) 170,170,80
   80 IF (ETIME(K)-100000.) 120,90,120
   90 IF (INDEX) 170,110,100
  100 IF (ISO) 170,170,150
  110 IF (ISO) 150,170,170
  120 IF (INDEX) 170,140,130
  130 IF (ISO) 160,170,170
  140 IF (ISO) 170,170,160
C
  150 IABC=IABS(IEQU(K))
      XXX=XMTBF(IABC)
      KEQ=K
      CALL TTE
      GO TO 170
C
  160 ETIME(K)=100000.
  170 CONTINUE
  180 RETURN
      END
C
C
C
C
C
      SUBROUTINE STATUS
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
      COMMON/BETA/NRO(6,300),IB(6,300,8),NLINE(6)
      COMMON/EXTRA/ KS(20),ISW(31)
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON/NPH/ NSS(6),IFLAG(6),TITLE(6,31),SSTIME(6,31,2),ISS(6,31)
      COMMON /XSPARE/XFLAG,BUDGET,COST(20)
C
      KID=0
```

```
      NL1=NLINE(LL)
   10 DO 130 K=1,NL1
   12 KT=IB(LL,K,1)
   14 IF(KID-KT) 16,18,16
   16 ISUM=0
C
   18 IF(NRO(LL,K)) 130, 130,20
   20 DO 60 J=2,8
   30 KK=IABS(IB(LL,K,J))
      IF (KK) 70,70,40
   40 IF (ETIME(KK)) 60,60,50
   50 ISUM=ISUM+1
   60 CONTINUE
   70 CONTINUE
      IF (ISUM-NRO(LL,K)) 80,90,90
   80 ETIME(KT)=-1.
      GO TO 100
   90 ETIME(KT)=1.
  100 IF(KS(12))125,125,110
  110 WRITE(6,120)KT,ETIME(KT)
  120 FORMAT(1X3HKK=,I5,7H ETIME=,F10.5)
  125 KID=KT
  130 CONTINUE
      N=NSS(LL)+1
      DO 160 I=1,N
      J=ISS(LL,I)
      IF (ETIME(J)) 140,140,150
  140 ISW(I)=-1
      GO TO 160
  150 ISW(I)=1
  160 CONTINUE
      KZZ=0
      RETURN
      END
C
C
C
C
      SUBROUTINE APPLE
      DIMENSION IPRNT(50),ICHLD(50),MKBA(100)
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
      COMMON/BETA/NRO(6,300),IB(6,300,8),NLINE(6)
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON /TIGAP/ UP4,XNUM,BAPRIN,AVA,XPCAP,RUNID(19),TYCOON(500)
     +,COUNTB(500),XTCUM
      COMMON/RUNAP/ITEMP2,DELT,ISSA(31),ISSC
```

```
      COMMON/NPH/NSS(6),IFLAG(6),TITLE(6,31),SSTIME(6,31,2),ISS(6,31)
      COMMON /PACKAP/ IBNUM( 6,500),ISYS( 6),F(200,4)
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
C
      IF(BAPRIN)790,90,90
   90 JCOUNT=0
C
  100 IPTR=0
      L=LL
      IF(ITEMP2)240,105,107
  105 K=IBNUM(L,ISYS(L)-500)
      GOTO 108
  107 KSS=ISSA(ISSC)
      K=IBNUM(L,ISS(L,KSS)-500)
  108 KID1=IB(L,K,1)
  110 NN=2
C
  120 DO 210 N=NN,8
      IGRP=IB(L,K,N)
      IF(IGRP)240,212,140
  140 IF  (ETIME(IGRP))  150,150,210
  150 IF  (IGRP-500)  170,170,160
C
  170 IF  (JCOUNT)  240,200,180
  180 DO  190  I=1,JCOUNT
      IF  (MKBA(I)-IGRP)  190,210,190
  190 CONTINUE
  200 CONTINUE
      JCOUNT=JCOUNT+1
      MKBA(JCOUNT)=IGRP
  210 CONTINUE
  212 IF(K-1)220,220,214
  214 KID2=IB(L,K-1,1)
      IF(KID1-KID2)220,216,220
  216 K=K-1
      GOTO 108
  220 IF  (IPTR)  240,260,230
C
  230 K=IPRNT(IPTR)
      KID1=IB(L,K,1)
      NN=ICHLD(IPTR)
      IPTR=IPTR-1
      GOTO 120
C
  160 IF  (N-8)  165,167,240
C
  165 IPTR=IPTR+1
      IPRNT(IPTR)=K
```

```
      ICHLD(IPTR)=N+1
  167 K=IBNOM(L,IGRP-500)
      GOTO 108
  240 WRITE (6,250)
  250 FORMAT (12H APPLE ERROR)
      GO TO 300
C
  260 IF(ITEMP2) 240,265,262
  262 ISSC=ISSC-1
      IF (ISSC) 240,265,100
  265 FCOUNT=FLOAT(JCOUNT)
      IF (ITEMP2) 270,270,280
C
  270 DO 275 I=1,JCOUNT
  275 TYCOON(MKBA(I))=TYCOON(MKBA(I))+DELT/FCOUNT
      GOTO 300
C
  280 DO 290 I=1,JCOUNT
  290 COUNTB(MKBA(I))=COUNTB(MKBA(I))+1/FCOUNT
  300 CONTINUE
      RETURN
C
  790 CONTINUE
      WRITE (6,800) (RUNID(I),I=1,19)
  800 FORMAT(1H1,3X,19A4//)
      WRITE (6,810)
  810 FORMAT(32X,19HCRITICAL EQUIPMENTS//32X,18HUNAVAILABILITY AND/    27
     1X25HPERCENT OF UNAVAILABILITY//)
      WRITE (6,820)
  820 FORMAT (24X4HNAME,17X7HNUM HRS,11X5HUNAVA,2X7HPERCENT,6X8HEQU TYPE
     1,5X7HEQU NUM/)
C
      IF (AVA-1.) 830,880,830
  830 TR=TYCOON(1)
      INDEX=1
      DO 850 I=2,NEQ
      TRR=TYCOON(I)
      IF (TR-TRR) 840,850,850
  840 TR=TRR
      INDEX=I
  850 CONTINUE
      TYCUM=TYCOON(INDEX)/TT3
      TYCUM2=TYCOON(INDEX)/(TT3-UP4)*100.
      IF (TYCOON(INDEX)) 860,880,860
  860 IXX=IABS(IEQU(INDEX))
      WRITE (6,870) (F(IXX,J),J=1,4),TYCOON(INDEX),TYCUM,TYCUM2,IXX
     1,INDEX
  870 FORMAT (20X4A4,F20.4,4XF8.4,F8.2,8XI4,10XI4)
```

```
      TYCOON(INDEX)=0.0
      GO TO 830
  880 WRITE (6,800)  (RUNID(I),I=1,19)
      WRITE (6,910)
  910 FORMAT(32X,19HCRITICAL EQUIPMENTS//32X,17HUNRELIABILITY AND/   27X
     127HPERCENT OF MISSION FAILURES//)
      WRITE (6,920)
  920 FORMAT  (12X11HDESCRIPTION,8X3HNO.,6X6HUNREL  ,3X7HPERCENT,2X13HEQUI
     1P  EQUIP /28X8HFAILURES,22X10HTYPE    NO.)
      IF (XPCAP-1.) 930,1090,930
C
  930 INEWA=0
      DO 950 I=1,NEQ
      IF (COUNTB(I)) 950,950,940
  940 INEWA=INEWA+1
      MKBA(INEWA)=I
  950 CONTINUE
C
      TOTAL=XNUM-XTCUM
  955 IF (INEWA-1) 1010,975,952
  952 INDEX=MKBA(1)
      NN=1
      TR=COUNTB(INDEX)
      DO 970 I=2,INEWA
      IF (TR-COUNTB(MKBA(I))) 960,970,970
  960 INDEX=MKBA(I)
      NN=I
      TR=COUNTB(INDEX)
  970 CONTINUE
  977 UNREL=TR/XNUM
      PERC=TR/TOTAL*100.
      IND=IABS(IEQU(INDEX))
      WRITE(6,990)  (F(IND,J),J=1,4),TR,UNREL,PERC,IND,INDEX
  990 FORMAT  (9X4A4,3XF6.1,5XF6.4,3XF6.2,4XI4,3XI4)
      MKBA(NN)=MKBA(INEWA)
      INEWA=INEWA-1
      GOTO 955
  975 INDEX=MKBA(1)
      TR=COUNTB(INDEX)
      GOTO 977
 1010 JNUM=IFIX(XNUM)
      WRITE (6,1020)  JNUM
 1020 FORMAT (//9X19HTOTAL NO. MISSIONS=,I4)
      ITOTAL=TOTAL
      WRITE (6,1030)  ITOTAL
 1030 FORMAT  (9X27HTOTAL NO. MISSION FAILURES=,I4)
 1090 RETURN
      END
```

```
C
C
C
C
      SUBROUTINE SPARES
C
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON /TYP/EX(2,200),ISPARE(3,200),IUSED(3,200),IIUSED(3,200)
      COMMON /CSPARE/ SPR1,SPR2,SPR3,SPR4,SPR5,SPR6,SPR7,SPR8,SPR9
     1,SPR10,SPR11,SPR12,SPR13,SPR14,ITMPOP(200)
C    OREILLY ADD
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
      COMMON /KSPARE/JTIME,TOTSPR
      IF(XFLAG-1.) 5,2,3
    2 CALL MSPARE
      WRITE (6,22)
      GO TO 101
    3 CALL GSPARE
      WRITE (6,22)
      GO TO 101
    5 CUT=SPR1
      XAVAIL=.9
      XBUDL=.85*BUDGET
      XBUDH=1.05* BUDGET
      WRITE(6,301)XBUDH
  301 FORMAT(/1X,5HBUDH ,F8.2)
      HIGH=1.
      LOW =0.0
      WRITE (6,6)
    6 FORMAT (/1X,33HSPARES BEING COMPUTED USING FLSIP)
      WRITE(6,303)XAVAIL
C    OREILLY STOP
      DO 10 I=1,NTYPE
      ITMPOP(I)=0
   10 CONTINUE
      DO 20 I=1,NEQ
      ITMPOP(IEQU(I))=ITMPOP(IEQU(I))+1
   20 CONTINUE
   25 DO 90 I=1,NTYPE
      EX90DD=((8766./XMTBF(I))/4.)*ITMPOP(I)
      IF(EX90DD-1.) 60,30,30
C
   30 PRBSUM=EXP(-EX90DD)
      DUM=PRBSUM
      KFACT=1
```

```
      K=0
   40 K=K+1
      KFACT=KFACT*K
      PRBSUM=PRBSUM+DUM*(EX90DD**K)/KFACT
      IF(PRBSUM-XAVAIL) 40,50,50
   50 ISPARE(1,I)=K
      GO TO 90
   60 IF(4.*EX90DD-CUT) 80,80,70
C
   70 ISPARE(1,I)=1
      GO TO 90
   80 ISPARE(1,I)=0
   90 CONTINUE
      XSUM=0.0
      DO 95 I=1,NTYPE
      XSUM1=ISPARE(1,I)*COST(I)
      XSUM=XSUM+XSUM1
   95 CONTINUE
      WRITE(6,302)XSUM
  302 FORMAT(/1X,5HXSUM ,F8.2)
      IF (XSUM-XBUDH) 200,200,205
   97 WRITE(6,98) XAVAIL
   98 FORMAT(/1X,44H,PSLIP ALLOWS CONSTRAINED BY BUDGET, XAVAIL= ,F8.6)
   99 DO 100 I=1,NTYPE
      DO 100 J=2,3
      ISPARE(J,I)=0
  100 CONTINUE
C   OREILLY ADD
      WRITE (6,22)
   22 FORMAT(/1X11HSPARES TYPE,6X4HSHIP,4X6HTENDER,6X4HBASE,12X6HFACTOR)
  101 RETURN
  200 IF(XAVAIL-.9) 97,99,99
  205 IF(XAVAIL-0.1) 208,208,206
  206 XAVAIL=XAVAIL-.05
      WRITE(6,303)XAVAIL
      GO TO 25
  208 DO 215 I=1,NTYPE
      J=1
      ISPARE(J,I)=0
  215 CONTINUE
      GO TO 97
C     GO TO 25
C   OREILLY STOP
      END
C
C
C
C
```

```
C
      SUBROUTINE MSPARE
C
C     MARGINAL ANALYSIS MODEL WITH COST CONSTRAINT READ IN SEPERATELY
C
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON /TYP/EX(2,200),ISPARE(3,200),IUSED(3,200),IIUSED(3,200)
      COMMON /CSPARE/ SPR1,SPR2,SPR3,SPR4,SPR5,SPR6,SPR7,SPR8,SPR9
     1,SPR10,SPR11,SPR12,SPR13,SPR14,ITMPOP(200)
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
      COMMON /KSPARE/JTIME,TOTSPR
      DIMENSION PRBSUM(201)
      DIMENSION PRBSUA(201)
      DIMENSION PRBSUD(201)
      DIMENSION DUM(201)
      DIMENSION K(201)
      DIMENSION KFACT(201)
      DIMENSION EX90DD(201)
      DIMENSION PRBSUE(201)
C
      NTYPE1=NTYPE+1
      COST(NTYPE1)=9.E10
      PRBSUD(NTYPE1)=0
      BUDLEF=BUDGET
      SFLAG=0
      WRITE (6,1)
    1 FORMAT(/1X,48HSPARES WILL BE DETERMINED WITH MARGINAL ANALYSIS)
      WRITE (6,2) BUDLEF
    2 FORMAT(/1X,10HBUDGET IS ,F8.0)
C
C    SET INITIAL STOCKS TO ZERO (SHIP/TENDER/DEPOT)
C
      DO 5 I=1,NTYPE
      DO 5 J=1,3
      ISPARE(J,I)=0
    4 FORMAT(/1X,24HSPARE MATRIX SET TO ZERO)
    5 CONTINUE
C    DETERMINE EXPECTED FAILURES IN 90 DAYS AND DETERMINE PROBABILITY
C    OF NO STOCKOUTS IN 90 DAYS IF ZERO SPARES ARE CARRIED.
C
      DO 6 I=1,NTYPE
      ITMPOP(I)=0
    6 CONTINUE
      DO 7 I=1,NEQ
      ITMPOP(IEQU(I))=ITMPOP(IEQU(I))+1
```

```
    7 CONTINUE
      DO 10 I=1,NTYPE
      EX90DD(I)=((8766./XMTBF(I))/4.)*ITMPOP(I)
      PRBSUM(I)=EXP(-EX90DD(I))
      DUM(I)=PRBSUM(I)
    8 FORMAT(/1X,17HITMPOP DETERMINED)
    9 FORMAT(/1X,16HEX90DD FOR ITEM ,I4,3X,F8.3)
   10 CONTINUE
   12 FORMAT(/1X,16HITMPOP FOR ITEM ,I4,4H IS ,I4)
   13 FORMAT(/1X,18HNTYPE AND NEQ ARE ,I4,I4)
   14 FORMAT(/1X,11HIEQU(I) IS ,I4)
C
C    K = NUMBER OF SPARES
C
      DO 20 I=1,NTYPE
      K(I)=1
      KFACT(I)=1
      WRITE (6,15) I,COST(I)
   15 FORMAT(/1X,17HTHE COST OF ITEM ,I4,4H IS ,F8.2)
   20 CONTINUE
C
C    DETERMINE PROBABILITY OF NO STOCKOUTS WITH ONE MORE SPARE THAN
C    PRBSUM.
C
      DO 25 I=1,NTYPE
      PRBSUA(I)=PRBSUM(I)+DUM(I)*(EX90DD(I)**K(I))/KFACT(I)
   25 CONTINUE
C
C    CALCULATE MARGINS BETWEEN PRBSUMA AND PRBSUM
C
      DO 30 I=1,NTYPE
      PRBSUE(I)=PRBSUA(I)-PRBSUM(I)
      PRBSUD(I)=PRBSUE(I)/COST(I)
   30 CONTINUE
C
C    SELECT LARGEST MARGIN
C
   31 I=1
      DO 50 J=2,NTYPE1
      IF(BUDLEF-COST(I)) 40,35,35
C
   35 SFLAG=1
      IF(PRBSUD(J)-PRBSUD(I)) 50,50,45
C
   40 I=J
      GO TO 50
C
   45 IF(BUDLEF-COST(J)) 50,40,40
```

```
C
   50 CONTINUE
C
C    IF ONE MORE OF ANY SPARE IS ALLOWED, INCREMENT SPARES ALLOWANCE,
C    OR ELSE QUIT.
C
   55 IF(SPLAG-1.) 100,60,100
C
C    IF ONE MORE SPARE IS ALLOWED, INCREMENT SPARES ALLOWANCE AND
C    ADJUST REMAINING BUDGET LEFT.
C
   60 ISPARE(1,I)=ISPARE(1,I)+1
      BUDLEF=BUDLEF-COST(I)
      K(I)=K(I)+1
      PRBSUM(I)=PRBSUA(I)
      PRBSUE(I)=PRBSUE(I)*EX90DD(I)/K(I)
      PRBSUD(I)=PRBSUE(I)/COST(I)
      PRBSUA(I)=PRBSUA(I)+PRBSUE(I)
      SFLAG=0
      GO TO 31
C
  100 WRITE (6,101)
  101 FORMAT(/1X,29HALL SPARES HAVE BEEN COMPUTED)
      RETURN
      END
C
C
C
C
C
C
      SUBROUTINE GSPARE
C
C  AVAILABILITY ROUTINE DEVELOPED BY MAN WON JEE
C
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,IL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON /TYP/EX(2,200),ISPARE(3,200),IUSED(3,200),IIUSED(3,200)
      COMMON /CSPARE/ SPR1,SPR2,SPR3,SPR4,SPR5,SPR6,SPR7,SPR8,SPR9
     1,SPR10,SPR11,SPR12,SPR13,SPR14,ITMPOP(200)
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
      COMMON /KSPARE/JTIME,TOTSPR,COMB(10000),COMBA(10000),SER(100)
      INTEGER NOSPRS,COMB,COMBA,SER
      DIMENSION LAMBDA(200),JSPARE(50,200),ETA(200),THETA(200)
      DIMENSION DELTA(200),XPRES1(50),XPRES2(50)
      COMMON /GEALG/NOSPRS,AVAIL(200,50),CCOST(200,50),SPRS(200,50)
```

```
      REAL JSPARE,LAMBDA,THETA,ETA,DELTA,IEXP,EMLT,TOD,PROD,XPRES1
      REAL XPRES2,XK,XLAST,FKR,FACTOR,SUMK,EMET,TODSQ,TSQOD3,XLAST1,PKL
      REAL PROD1,SUMK1,SUMK11,AVAIL,BVAR,FCTOR2,JTIME1,JTIME2,GTIME
      REAL CCOST
      INTEGER AVAR,R,FCTOR1,LVAR,K,TOTSPR,JVAR,SPRS
C
C
      WRITE(6,1)
    1 FORMAT (/1X,39HSPARES BEING COMPUTED USING JEE FORMULA)
      WRITE(6,2)JTIME
    2 FORMAT (/1X,9HJTIME IS ,I8)
      GTIME=FLOAT(JTIME)
    4 FORMAT(/1X,8HTIME IS ,F8.1)
      WRITE(6,3)TOTSPR
    3 FORMAT (/1X,10HTOTSPR IS ,I4)
C   SET INITIAL STOCKS TO ZERO (SHIP/TENDER/DEPOT)
C
      DO 5 I=1,NTYPE
      DO 5 J=1,3
      ISPARE(J,I)=0
    5 CONTINUE
    6 FORMAT(/1X,24HSPARE MATRIX SET TO ZERO)
C
C   SET GSPARE AVAILABILITY MATRIX TO ZERO
C
      AVAR=TOTSPR+1
      DO 10 I=1,NTYPE
      DO 10 J=1,TOTSPR
      AVAIL(I,J)=0
   10 CONTINUE
C
C   CALCULATE LAMBDAS, ETAS, THETAS, AND DELTAS
C
      DO 13 I=1,NTYPE
      LAMBDA(I)=1/XMTBF(I)
   13 CONTINUE
C
      DO 14 I=1,NTYPE
      ETA(I)=1/XMTTR(I)
   14 CONTINUE
C
      DO 15 I=1,NTYPE
      THETA(I)=LAMBDA(I)*ETA(I)
   15 CONTINUE
C
      DO 16 I=1,NTYPE
      DELTA(I)=ETA(I)-LAMBDA(I)
   16 CONTINUE
```

```
C
C     CALCULATE GSPARE AVAILABILITIES WITH ZERO SPARES
C
         DO 18 I=1,NTYPE
         AVAIL(I,1)=EXP(-LAMBDA(I)*GTIME)
         SPRS(I,1)=0
         CCOST(I,1)=0.0
   18    CONTINUE
C
C     CALCULATE AVAILABILITIES FOR EACH I (THRU NTYPE) WITH K SPARES (THRU
C     TOTSPR)
C
         DO 300 I=1,NTYPE
C     FIND XPRES1: FIRST HALF OF AVAIL EQUATION
C     FOR K=1, WE FIND SUM TO BE:
         EMLT=EXP(-LAMBDA(I)*GTIME)
         TOD=THETA(I)/DELTA(I)
         PROD=TOD
C
         XPRES1(1)=(GTIME-1./DELTA(I))*TOD*EMLT
C
C     NOW INITIALIZE OTHER VARIABLES
         XK=GTIME
         XLAST=1
         FKR=1
C
         IF (TOTSPR-1) 110,110,30
   30    DO 100 K=2,TOTSPR
C
C     CALCULATE FKR FOR R=1 USING RECURSIVE EXP NO.1
C
         FKR=K*XLAST/(K-1)**2
         XLAST=FKR
         JVAR=K-1
         JTIME1=GTIME**JVAR
         JTIME2=JTIME1/DELTA(I)
         FACTOR=(-1.)*JTIME2
         SUMK=FACTOR*FKR
  552    FORMAT(/1X,7HSUMK = ,E10.4)
C
C     NOW SUM OVER R=2 TO K; CALCULATE USING RECURSIVE EXP NO.2
C
         DO 50 R=2,K
         FKR=(K+(R-1))*(K-(R-1))*FKR/R
         XK=XK*GTIME/K
         XPRES1(K)=(XK+SUMK)*EMLT*PROD
  100    CONTINUE
C
```

```
C   FIND XPRES2: SECOND HALF OF AVAIL EXPRESSION
C   FOR K=1, WE FIND SUM TO BE:
        IF(ETA(I)*GTIME-25.0) 110,110,109
  109 EMET=0
        GO TO 117
  110 EMET=EXP(-ETA(I)*GTIME)
  512 FORMAT(/1X,26HI,EMET,ETA, AND TIME ARE: ,I4,E12.5,F8.5,F8.1)
  117 TODSQ=THETA(I)/DELTA(I)**2
        XPRES2(1)=TODSQ*EMET
        IF(TOTSPR-1) 204,204,120
C    FOR K=2, WE FIND SUM TO BE:
  120 TSQOD3=TODSQ*(THETA(I)/DELTA(I))
        XPRES2(2)=(-1.)*TSQOD3*(GTIME+(3/DELTA(I)))*EMET
        IF (TOTSPR-2) 204,204,140
C
CNOW INITIALIZE VARIABLES
C
  140 XLAST1=3/DELTA(I)
        FCTOR2=GTIME
        FKL=3/DELTA(I)
        PROD1=THETA(I)**2/DELTA(I)**3
        FCTOR1=-1.
C
        DO 205 K=3,TOTSPR
C
C   CALCULATE FKL FOR L=1 USING RECURSIVE EXP NO. 3
C
        FKL=XLAST1*GTIME*(1./(K-2))*(1./K)*(K+1)
        XLAST1=FKL
        SUMK1=FKL
C
C   NOW SUM OVER L=2 TO K-1 USING RECURSIVE EXP NO. 4
C
        LVAR=K-1
        DO 150 L=2,LVAR
        FKL=FKL*(K-L)*(K+L)*(1./L)
        FKL=FKL/(GTIME*DELTA(I))
        SUMK1=SUMK1+FKL
  150 CONTINUE
        FCTOR2=FCTOR2*GTIME/(K-1)
        SUMK11=FCTOR2+SUMK1
C
  204 PROD1=PROD1*(THETA(I)/DELTA(I))
        FCTOR1=FCTOR1*(-1.)
        XPRES2(K)=FCTOR1*PROD1*EMET*SUMK11

  205 CONTINUE
```

```
C
C  BECAUSE 0 SPARES AVAILABILITY IS INDEXED AS 1 DO:
      DO 250 K=1,TOTSPR
      AVAIL(I,K+1)=XPRES1(K)+XPRES2(K)+AVAIL(I,K)
      CCOST(I,K+1)=COST(I)*K
      SPRS(I,K+1)=K
  250 CONTINUE
  300 CONTINUE
      DO 450 I=1,NTYPE
      WRITE(6,350) I
  350 FORMAT (/1X,29HAVAILABILITY MATRIX FOR SPARE,I3,4H IS:)
      DO 440 J=1,AVAR
      WRITE(6,370) I,SPRS(I,J),CCOST(I,J),AVAIL(I,J)
  370 FORMAT(/1X,I4,2X,I4,2X,F8.2,2X,F8.6)
  440 CONTINUE
  450 CONTINUE
      CALL GEEALG
      RETURN
      END
C
C
C
C
C
C
C
C
      SUBROUTINE GEEALG
C
C  ALGORTIHM DEVELOPED BY GEE FOR DETERMINING OPTIMAL
C  SPARES COMBINATIONS
C
      COMMON /ALPHA/DNT2,ENDPHA,ICRI,IFF,IFR,INUM,IOPT,JBB,KEQ,KKK,KZZ
     1,KK1,KS1,LL,LLLAST,NEQ,NPH,NTYPE,NUM,REDAD2,REDAD1(100),RELP,RED2
     2,RELPY,REPOL,STPHAS,TP,T1,XCUM,TT3,UP3,IFFEOP,T3,TIME,T3SUM
      COMMON /N/IEQU(500),KEQU(500),ETIME(1000),XMTBF(200),XMTTR(200)
      COMMON /TYP/EX(2,200),ISPARE(3,200),IUSED(3,200),IIUSED(3,200)
      COMMON /CSPARE/ SPR1,SPR2,SPR3,SPR4,SPR5,SPR6,SPR7,SPR8,SPR9
     1,SPR10,SPR11,SPR12,SPR13,SPR14,ITMPOP(200)
      COMMON /KSPARE/JTIME,TOTSPR,COMB(9999),COMBA(9999),SER(100)
      INTEGER NOSPRS,COMB,COMBA,SER
      COMMON /XSPARE/XFLAG,BUDGET,COST(201)
      COMMON /GEALG/NOSPRS,AVAIL(200,50),CCOST(200,50),SPRS(200,50)
      DIMENSION LAMBDA(200),JSPARE(50,200),ETA(200),THETA(200)
      DIMENSION DELTA(200),XPRES1(50),XPRES2(50)
      INTEGER OPT,LOPT,MATV,CSPRS(1111,20),FIX,FIXA,IVARA,IVARB
      INTEGER IVAR1,IVAR2,NCAND,PK,PJ,PL,PM,LJ,LM,LK,LL,IVAR(999)
      REAL AVAILO(9999),CCOSTO(9999),PAVAIL,PCOST,NCOST,NAVAIL
```

```
      REAL JSPARE,LAMBDA,THETA,ETA,DELTA,IEXP,EMLT,TOD,PROD,XPRES1
      REAL XPRES2,XK,XLAST,FKR,FACTOR,SUMK,EMET,TODSQ,TSQOD3,XLAST1,PKL
      REAL PROD1,SUMK1,SUMK11,AVAIL,BVAR,PCTOR2,JTIME1,JTIME2,GTIME
      REAL CCOST
      INTEGER AVAR,R,PCTOR1,LVAR,K,TOTSPR,TOTSP,JVAR,SPRS
      INTEGER HOLD7,HOLD8,COMBIN,OPT1,OPT2
C
C
      WRITE(6,1100)
C**********************************************************************
C**                                                                 **
C**     SET INITIAL VARIABLES.                                      **
C**                                                                 **
C**********************************************************************
      MATV=1
      TOTSP=TOTSPR+1
      HOLD7=0
      HOLD8=0
      COMBIN=101
C**********************************************************************
C**                                                                 **
C**     CHANGE AVAIL,CCOST AND SPRS FIGURES TO AVAILO,CCOSTO,CSPRS. **
C**                                                                 **
C**********************************************************************
      DO 20 I=1,NOSPRS
      J=I*10
        DO 15 K=1,TOTSP
        AVAILO(J)=AVAIL(I,K)
        CCOSTO(J)=CCOST(I,K)
        CSPRS(J,I)=SPRS(I,K)
        J=J+1
   15   CONTINUE
   20 CONTINUE
C**********************************************************************
C**                                                                 **
C**     CHECK FIRST INPUT COMBINATION                               **
C**                                                                 **
C**********************************************************************
      J=COMB(MATV)
      L=COMBA(MATV)
      IF(J-1.) 30,32,32
   30 WRITE(6,1101)
      GO TO 1000
C**********************************************************************
C**                                                                 **
C**     CHECK SUBSEQUENT INPUT COMBINATIONS                         **
C**                                                                 **
C**********************************************************************
```

```
   31 J=COMB(MATV)
      L=COMBA(MATV)
C*************************************************************************
C**                                                                     **
C**      IF J=0 THEN STOP                                               **
C**                                                                     **
C*************************************************************************
   32 IF(J-1.) 1200,33,33
   33 IF(J-70.) 36,34,55
   34 WRITE(6,1103)
      GO TO 1000
   36 J=J*10
      IF(L-70.) 37,34,45
   37 L=L*10
      IF(HOLD7-1.) 43,38,38
   38 IF(HOLD8-1.) 40,39,39
   39 WRITE(6,1103)
      GO TO 1000
C*************************************************************************
C**                                                                     **
C**   801 COMBINATION FROM 2 ORIGINAL INPUTS                            **
C**                                                                     **
C*************************************************************************
   40 OPT1=801
      HOLD8=COMBIN
      IVARA=J+TOTSPR
      IVARB=L+TOTSPR
      GO TO 125
C*************************************************************************
C**                                                                     **
C**      FIRST COMBINATION:RESULTING MATRIX = 701                       **
C**                                                                     **
C*************************************************************************
   43 OPT1=701
      HOLD7=COMBIN
      IVARA=J+TOTSPR
      IVARB=L+TOTSPR
      GO TO 125
   45 IF(HOLD7-L) 50,46,50
   46 OPT1=701
      HOLD7=COMBIN
      L=701
      IVARA=J+TOTSPR
      IVARB=IVAR(701)
      GO TO 125
   50 IF(HOLD8-L) 51,52,51
   51 WRITE(6,1103)
      GO TO 1000
```

```
C*******************************************************************
C**                                                               **
C**     J IS TO BE COMBINED WITH EXISTING 801 COMBINATION.        **
C**    RESULTING MATRIX = 801.                                    **
C**                                                               **
C*******************************************************************
   52 OPT1=801
      HOLD8=COMBIN
      L=801
      IVARA=J+TOTSPR
      IVARB=IVAR(801)
      GO TO 125
   55 IF(L-70.) 58,34,56
C*******************************************************************
C**                                                               **
C**     J AND L ARE EXISTING MATRIXES,RESULTING MATRIX = 701.     **
C**                                                               **
C*******************************************************************
   56 OPT1=701
      HOLD7=COMBIN
      HOLD8=0
      J=701
      L=801
      IVARA=IVAR(701)
      IVARB=IVAR(801)
      GO TO 125
   58 L=L*10
      IF(HOLD7-J) 60,59,60
   59 OPT1=701
      HOLD7=COMBIN
      J=701
      IVARA=IVAR(701)
      IVARB=L+TOTSPR
      GO TO 125
   60 IF(HOLD8-J) 51,62,51
C*******************************************************************
C**                                                               **
C**     L IS BEING ADDED TO EXISTING 801 COMBINATION.             **
C**     RESULTING MATRIX = 801.                                   **
C**                                                               **
C*******************************************************************
   62 OPT1=801
      HOLD8=COMBIN
      J=801
      IVARA=IVAR(801)
      IVARB=L+TOTSPR
C*******************************************************************
C**
```

```
C**      START COMPUTING NEW MATRIX COMBINATIONS. RESULTING             **
C**      MATRIX = 901 INITIALLY AND THEN CONVERTED TO 701 OR 801.       **
C**                                                                     **
C************************************************************************
  125 OPT=901
      FIX=901
      IVAR(FIX)=901
      FIXA=999
      IVAR1=J
      IVAR2=L
C************************************************************************
C**                                                                     **
C**      FIRST COMBINATION IS ALWAYS UPPER LEFT CORNER.                 **
C**                                                                     **
C************************************************************************
      IF(SER(MATV)-1.) 130,128,128
  128 AVAILO(OPT)=AVAILO(J)*AVAILO(L)
      GO TO 132
  130 AVAILO(OPT)=1.-((1.-AVAILO(J))*(1.-AVAILO(L)))
  132 CCOSTO(OPT)=CCOSTO(J)+CCOSTO(L)
C************************************************************************
C**                                                                     **
C**      TRANSFER J SPARES TO OPT SPARES.                               **
C**                                                                     **
C************************************************************************
      DO 145 I=1,NOSPRS
      IF(CSPRS(J,I)-1) 145,141,141
  141 CSPRS(OPT,I)=CSPRS(J,I)
  145 CONTINUE
C************************************************************************
C**                                                                     **
C**      TRANSFER L SPARES TO OPT SPARES.                               **
C**                                                                     **
C************************************************************************
      DO 150 I=1,NOSPRS
      IF(CSPRS(L,I)-1) 150,146,146
  146 CSPRS(OPT,I)=CSPRS(L,I)
  150 CONTINUE
      IVAR(FIX)=IVAR(FIX)+1
      LJ=J
      LL=L
C**********************************************************************
C  CHECK TO SEE IF MAX COMBINATIONS HAVE BEEN COMPUTED
C**********************************************************************
  154 IF(FIXA-OPT) 288,288,155
  155 OPT=OPT+1
      NCAND=0
C************************************************************************
```

```
C**                                                                  **
C**      CHECK TO SEE IF MAX J REACHED.                              **
C**                                                                  **
C*********************************************************************
      IF(J-IVARA) 161,190,190
C*********************************************************************
C**                                                                  **
C**      NEXT POSSIBLE BEST COMBINATION IN QUAD III IS J+1,L.        **
C**                                                                  **
C*********************************************************************
  161 IF(SER(MATV)-1.) 163,162,162
  162 PAVAIL=AVAILO(J+1)*AVAILO(L)
      GO TO 164
  163 PAVAIL=1.-((1.-AVAILO(J+1))*(1.-AVAILO(L)))
  164 PCOST=CCOSTO(J+1)+CCOSTO(L)
      PJ=J+1
      PL=L
C*********************************************************************
C**                                                                  **
C**      CHECK TO SEE IF MIN L REACHED.                              **
C**                                                                  **
C*********************************************************************
      IF(L-IVAR2) 200,200,170
C*********************************************************************
C**                                                                  **
C**      NEXT POSSIBLE CANDIDATE IS J+1,L-1.                        **
C**                                                                  **
C*********************************************************************
  170 NCOST=CCOSTO(J+1)+CCOSTO(L-1)
      IF(SER(MATV)-1) 172,171,171
  171 NAVAIL=AVAILO(J+1)*AVAILO(L-1)
      GO TO 173
  172 NAVAIL=1.-((1.-AVAILO(J+1))*(1.-AVAILO(L-1)))
C*********************************************************************
C**                                                                  **
C**      NAVAIL MUST EXCEED PREVIOUS OPT AVAIL.                      **
C**                                                                  **
C*********************************************************************
  173 IF(AVAILO(OPT-1)-NAVAIL) 174,185,185
C*********************************************************************
C**                                                                  **
C**      NCOST MUST BE LESS THAN PREVIOUS PCOST.                     **
C**                                                                  **
C*********************************************************************
  174 IF(NCOST-PCOST) 175,500,180
C*********************************************************************
C**                                                                  **
C**      IF NAVAIL GT OPT AVAIL AND NCOST LT PCOST THEN J+1,L-1      **
```

```
C**     IS NEW BEST CANDIDATE.                                        **
C**                                                                   **
C*********************************************************************
  175 PAVAIL=NAVAIL
      PCOST=NCOST
      PJ=J+1
      PL=L-1
C*********************************************************************
C**                                                                   **
C**     CHECK TO SEE IF MIN L REACHED.                                **
C**                                                                   **
C*********************************************************************
  180 L=L-1
      IF(L-IVAR2) 181,181,170
C*********************************************************************
C**                                                                   **
C**     IF MIN L REACHED, GO BACK TO PREVIOUS OPT AND SEARCH          **
C**     QUAD II.                                                      **
C**                                                                   **
C*********************************************************************
  181 L=LL
      J=LJ
      GO TO 200
C*********************************************************************
C**                                                                   **
C**     SINCE NAVAIL IS TOO SMALL, ADD 1 TO J IF NOT AT MAX J.        **
C**                                                                   **
C*********************************************************************
  185 IF((J+1)-IVARA) 186,187,187
  186 J=J+1
      GO TO 170
C*********************************************************************
C**                                                                   **
C**     IF MAX J REACHED, GO BACK TO PREVIOUS OPT AND SEARCH QUAD II. **
C**                                                                   **
C*********************************************************************
  187 L=LL
      J=LJ
      GO TO 200
C*********************************************************************
C**                                                                   **
C**     IF NO CANDIDATE IN QUAD III, GO TO QUAD II.                   **
C**                                                                   **
C*********************************************************************
  190 NCAND=1
      GO TO 200
C*******************************************************************
C  COMPUTE MAX OPTIMAL IN UPPER RIGHT HAND QUADRANT
```

```
C**********************************************************************
C**********************************************************************
C**                                                                  **
C**      CHECK TO SEE IF MAX L REACHED.                              **
C**                                                                  **
C**********************************************************************
  200 IF(L-IVARB)  205,202,202
  202 IF(NCAND-1)  250,299,250
  205 IF(NCAND-1)  210,206,210
C**********************************************************************
C**                                                                  **
C**      NEXT CANDIDATE IS J,L+1.                                    **
C**                                                                  **
C**********************************************************************
  206 PCOST=CCOSTO(J)+CCOSTO(L+1)
      IF(SER(MATV)-1)  208,207,207
  207 PAVAIL=AVAILO(J)*AVAILO(L+1)
      GO TO 209
  208 PAVAIL=1.-((1.-AVAILO(J))*(1.-AVAILO(L+1)))
  209 PJ=J
      PL=L+1
      GO TO 220
C**********************************************************************
C**                                                                  **
C**      NEXT CANDIDATE IS J,L+1.                                    **
C**                                                                  **
C**********************************************************************
  210 NCOST=CCOSTO(J)+CCOSTO(L+1)
C**********************************************************************
C**                                                                  **
C**      NCOST MUST BE LT PCOST.                                     **
C**                                                                  **
C**********************************************************************
      IF(SER(MATV)-1)  213,212,212
  212 NAVAIL=AVAILO(J)*AVAILO(L+1)
      GO TO 214
  213 NAVAIL=1.-((1.-AVAILO(J))*(1.-AVAILO(L+1)))
C**********************************************************************
C**                                                                  **
C**      NAVAIL MUST BE LT OPT AVAIL.                                **
C**                                                                  **
C**********************************************************************
  214 IF(AVAILO(OPT-1.)-NAVAIL) 510,225,225
  215 PAVAIL=NAVAIL
      PCOST=NCOST
      PJ=J
      PL=L+1
C**********************************************************************
```

```
C**                                                              **
C**     NEXT CANDIDATE IS J-1,L+1.                               **
C**                                                              **
C*****************************************************************
  220 J=J-1
      IF(J-IVAR1) 250,210,210
  225 L=L+1
      IF(L-IVARB) 210,250,250
C*****************************************************************
C**                                                              **
C**   MAX COMBINATION FOR THIS OPT HAS BEEN REACHED.             **
C**                                                              **
C*****************************************************************
  250 AVAILO(OPT)=PAVAIL
      CCOSTO(OPT)=PCOST
      DO 255 I=1,NOSPRS
      IF(CSPRS(PJ,I)-1.)253,252,252
  252 CSPRS(OPT,I)=CSPRS(PJ,I)
  253 IF(CSPRS(PL,I)-1.)255,254,254
  254 CSPRS(OPT,I)=CSPRS(PL,I)
  255 CONTINUE
      IVAR(FIX)=IVAR(FIX)+1
      J=PJ
      L=PL
      LJ=PJ
      LL=PL
C**************************************************************
C  CHECK TO SEE IF BUDGET CONSTRAINT EXCEEDED
C**************************************************************
      IF(CCOSTO(OPT)-BUDGET) 257,290,290
C*****************************************************************
C**                                                              **
C**     CHECK FOR MAX J AND MAX L                                **
C**                                                              **
C*****************************************************************
  257 IF(J-IVARA) 154,258,258
  258 IF(L-IVARB) 154,259,259
  259 GO TO 290
C*****************************************************************
C**                                                              **
C**     BUDGET CONSTRAINT HAS BEEN EXCEEDED.                     **
C**                                                              **
C*****************************************************************
  288 WRITE(6,289)
  289 FORMAT(/1X,48HBUDGET FOR OPTIMAL COMBINATION CANNOT BE REACHED)
C*****************************************************************
C**                                                              **
C**     COMPUTATIONS FOR THIS MATRIX ARE COMPLETE.               **
```

```
C**
C*******************************************************************
  290 LOPT=OPT
      IVAR(FIX)=IVAR(FIX)-1.
      IF(OPT1-701.) 311,310,311
C*******************************************************************
C**                                                               **
C**     SET OPT1 MATRIX EQUAL TO CURRENT RESULTING MATRIX AND     **
C**     SET 901 MATRIX TO ZERO.                                   **
C**                                                               **
C*******************************************************************
  291 ITS=IVAR(FIX)
      OPT2=OPT1
      DO 293 I=901,ITS
      AVAILO(OPT2)=AVAILO(I)
      CCOSTO(OPT2)=CCOSTO(I)
            DO 292 K=1,NOSPRS
            CSPRS(OPT2,K)=CSPRS(I,K)
            CSPRS(I,K)=0
  292       CONTINUE
      OPT2=OPT2+1
  293 CONTINUE
C*******************************************************************
C**                                                               **
C**     SET IVAR(OPT1) = RESULTING MATRIX IVAR.                   **
C**                                                               **
C*******************************************************************
      IVAR(OPT1)=IVAR(FIX)-FIX+OPT1
      MATV=MATV+1
      COMBIN=COMBIN+1
      GO TO 31
C*******************************************************************
C**                                                               **
C**     MAX OPT REACHED ON PREVIOUS COMPUTATION.                  **
C**                                                               **
C*******************************************************************
  299 LOPT=OPT-1
      IVAR(FIX)=IVAR(FIX)-1.
      IF(OPT1-701.) 311,310,311
C*******************************************************************
C**                                                               **
C**     SINCE NEW MATRIX = 701,CROSS REF IT TO COMBIN.            **
C**                                                               **
C*******************************************************************
  310 HOLD7=COMBIN
      LOPT=LOPT-FIX+701
      GO TO 291
  311 IF(OPT1-801.)34,312,34
```

```
C*****************************************************************
C**                                                             **
C**     SINCE NEW MATRIX = 801,CROSS REF IT TO COMBIN.          **
C**                                                             **
C*****************************************************************
  312 HOLD8=COMBIN
      LOPT=LOPT-FIX+801
      GO TO 291
  500 IF(NAVAIL-PAVAIL) 180,180,175
  510 IF(NCOST-PCOST)215,515,220
  515 IF(NAVAIL-PAVAIL) 220,220,215
 1000 RETURN
 1200 DO 1250 I=1,NOSPRS
      ISPARE(1,I) =CSPRS(LOPT,I)
 1250 CONTINUE
      GO TO 1000
   17 FORMAT(/1X,16HSPARES FOR ITEM ,I4,9HAND LOPT ,I4,4HARE ,I4)
   21 FORMAT(/1X,10HCSPRS FOR ,I4,4HAND ,I4,4HARE ,I4,4HAND ,I4)
 1001 FORMAT(/1X,19HAVAIL AND COST FOR ,I4,4HARE ,F8.6,4HAND ,F8.2)
 1002 FORMAT(/1X,21HPAVAIL AND PCOST FOR ,I4,4HARE ,F8.6,4HAND ,F8.2)
 1003 FORMAT(/1X,21HNAVAIL AND NCOST FOR ,I4,4HARE ,F8.6,4HAND ,F8.2)
 1004 FORMAT(/1X,20HJ.GE.100 AND L.LE.99)
 1005 FORMAT(/1X,20HJ.LE.99 AND L.GE.100)
 1006 FORMAT(/1X,21HJ.GE.100 AND L.GE.100)
 1007 FORMAT(/1X,7HLOPT IS ,I4)
 1008 FORMAT(/1X,19HN,I,CSPRS(N,I) ARE ,3I4,F8.2)
 1009 FORMAT(/1X,34HJ,K,L,AVAIL(J,K) AND AVAILO(L) ARE ,3I4,2F8.6)
 1010 FORMAT(/1X,14HCSPRS FOR OPT ,I4,10HAND SPARE ,I4,4HARE ,I4,X,F8.2)
 1011 FORMAT(/1X,9HNOSPRS = ,I4)
 1012 FORMAT(/1X,19HL,I,CSPRS(L,I) ARE ,I4,I4,I4)
 1013 FORMAT(/1X,19HMATV,SER(MATV) ARE ,2I4)
 1014 FORMAT(/1X,28HI,JJ,K,AV(JJ),CC(JJ),SP(JJ) ,3I4,F8.6,F8.2,I4)
 1015 FORMAT(/1X,7HNCOST= ,F8.2)
 1016 FORMAT(/1X,12HCHECK POINT ,I4)
 1017 FORMAT(/1X,7HMATV = ,I4,15HAND SER(MATV)= ,I4)
 1018 FORMAT(/1X,29HJ,L,AVAILO(J),AVAILO(L), ARE ,I4,I4,2F8.6)
 1019 FORMAT(/1X,33HFIX,AVAILO(FIX),CSPRS(FIX,I) ARE ,I4,F8.6,I4)
 1100 FORMAT(/1X,34HJEEALG SUBROUTINE HAS BEEN ENTERED)
 1101 FORMAT(/1X,44HNO SPARES COMPUTED;FIRST INPUT WAS STOP CODE)
 1102 FORMAT(/1X,41HINPUT FOR FIRST COMBINATION MUST BE LE 68)
 1103 FORMAT(/1X,34HINVALID COMBINATION HAS BEEN INPUT)
 1105 FORMAT(/1X,24HJ,I, AND CSPRS(J,I) ARE ,3I4)
 1120 FORMAT(/1X,7HHOLD7= ,I4)
 1121 FORMAT(/1X,7HHOLD8= ,I4)
      END
```

APPENDIX D

TIGER PROGRAM OUTPUT EXAMPLES

The TIGER simulator produces both standard and optional outputs. The various options are discussed in Appendix B under the Printout Option Card. The optional output used for this research was the management summary printout. It first displays most of the user's input, the allowance determination model used to compute repair part allowances (if one was used), and the number of repair parts being used. An example of this output is shown in Table XVIII. A detailed explanation of the entries on Table XVIII is provided in Reference 4.

The TIGER simulator then prints a message every time the system goes down indicating which components are down and when they will come back up. An example of this output is shown in Table XIX. A detailed explanation of the entries on Table XIX is provided in Reference 4. Since this portion of the output was voluminous and not useful for analysis during this research, it was suppressed.

The TIGER simulator then prints the cumulative measures of effectiveness for the system after each group of 50 missions has been simulated. An example of this output is shown in Table XX. A detailed explanation of the entries on Table XX is provided in Reference 4. Since this portion of the output was voluminous and not useful until all simulations were completed, it was suppressed until the last mission simulation was completed.

The TIGER simulator then produces tables which summarize data about specific equipment failures, the number of repair parts used, and critical equipments. An example of this

output is shown in Table XXI. A detailed explanation of the entries on Table XXI is provided in Reference 4.

TABLE XVIII

Sample TIGER Model Output

```
    1
 90 DAY .25 FLSIP EVALUATION OF SYSTEM Z
 XXXXXXXXXXXXXXXXXXXX   TIGER   XXXXXXXXXXXXXXXXXXX
 X NAVSEC 6112 LUETJEN+MANDEL+VAIL+ALLEY+BROWN XX
 XNPS IBM/360 VERSION LT. J. LEATHER THESES 9/80XX
 XAS AMENDED BY LCDR. P.J. O'REILLY THESES 12/81XX

RANDOM SEED IS 2222
  1000   1000   1.00    1.26    2222     1

 PHASE SEQUENCE  TYPE   DURATION   CUM TIME
            1      1     2160.00    2160.00

      1  0  0  0  0  0  0  0  0  0  0  0  0  0
  0
      1.00   0.0   1.00    1.00

TYPE  NAME      MTBF      MTTR      DC      ADT1  ADT2
   1  ITEM A   1720.0    10.00    1.000    0.0   0.0
   2  ITEM B   1720.0    10.00    1.000    0.0   0.0
   3  ITEM C   3000.0    10.00    1.000    0.0   0.0

TYPE EQUIPMENT
   1  1  0  0  0  0  0  0  0  0  0  0  0  0  0
   2  2  0  0  0  0  0  0  0  0  0  0  0  0  0
   3  3  0  0  0  0  0  0  0  0  0  0  0  0  0

SPARES WILL BE DETERMINED WITH MARGINAL ANALYSIS

BUDGET IS     850.

THE COST OF ITEM   1 IS   200.00

THE COST OF ITEM   2 IS    50.00

THE COST OF ITEM   3 IS   100.00

ALL SPARES HAVE BEEN COMPUTED

SPARES TYPE    SHIP    TENDER    BASE      FACTOR
        1        2        0        0       999.00
        2        5        0        0       999.00
        3        2        0        0       999.00
```

TABLE XIX

Mission Abort Printouts

```
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -849.1533
IN PHASE  1 SEQ  1      MISSION   203    ABORTED AT TIME  191.1857  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -417.9463
IN PHASE  1 SEQ  1      MISSION   204    ABORTED AT TIME   93.9582  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -323.1365
IN PHASE  1 SEQ  1      MISSION   205    ABORTED AT TIME  415.3679  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -698.0110
                    EQUIPMENT      3 DOWN IT WILL COME UP AT        -416.7654
IN PHASE  1 SEQ  1      MISSION   206    ABORTED AT TIME  209.5827  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -448.9041
IN PHASE  1 SEQ  1      MISSION   207    ABORTED AT TIME  795.8403  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -823.4023
IN PHASE  1 SEQ  1      MISSION   208    ABORTED AT TIME   76.1077  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -188.2360
IN PHASE  1 SEQ  1      MISSION   209    ABORTED AT TIME  336.2976  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      3 DOWN IT WILL COME UP AT        -374.0742
                    EQUIPMENT      4 DOWN IT WILL COME UP AT        -498.3687
IN PHASE  1 SEQ  1      MISSION   210    ABORTED AT TIME  277.7280  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -335.0073
IN PHASE  1 SEQ  1      MISSION   211    ABORTED AT TIME  294.8416  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      3 DOWN IT WILL COME UP AT        -392.6448
                    EQUIPMENT      4 DOWN IT WILL COME UP AT        -318.1665
IN PHASE  1 SEQ  1      MISSION   212    ABORTED AT TIME  394.6638  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -410.0244
IN PHASE  1 SEQ  1      MISSION   213    ABORTED AT TIME   23.7935  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -111.0121
IN PHASE  1 SEQ  1      MISSION   214    ABORTED AT TIME 1001.8452  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT       -1068.9128
IN PHASE  1 SEQ  1      MISSION   215    ABORTED AT TIME  436.3381  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -503.7354
IN PHASE  1 SEQ  1      MISSION   216    ABORTED AT TIME   34.6739  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      3 DOWN IT WILL COME UP AT         -36.1202
                    EQUIPMENT      4 DOWN IT WILL COME UP AT        -106.7290
IN PHASE  1 SEQ  1      MISSION   217    ABORTED AT TIME   73.8003  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -151.3528
IN PHASE  1 SEQ  1      MISSION   218    ABORTED AT TIME   48.1007  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -204.9000
IN PHASE  1 SEQ  1      MISSION   219    ABORTED AT TIME  146.9315  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -339.9929
IN PHASE  1 SEQ  1      MISSION   220    ABORTED AT TIME  289.7063  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -312.8232
IN PHASE  1 SEQ  1      MISSION   221    ABORTED AT TIME 1217.7837  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT       -1234.5176
IN PHASE  1 SEQ  1      MISSION   222    ABORTED AT TIME  460.4075  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -512.3968
IN PHASE  1 SEQ  1      MISSION   223    ABORTED AT TIME  718.1361  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      1 DOWN IT WILL COME UP AT        -369.2776
IN PHASE  1 SEQ  1      MISSION   224    ABORTED AT TIME  458.2410  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      2 DOWN IT WILL COME UP AT        -509.7029
IN PHASE  1 SEQ  1      MISSION   225    ABORTED AT TIME  130.7750  BECAUSE SYST  EXCEEDED  DOWNTIME   0.0  HRS.
                    EQUIPMENT      3 DOWN IT WILL COME UP AT        -132.8455
```

TABLE XX

50 Mission Summary Data

```
                                         INSTANT AVAILABILITY         IS 1.[illegible]
                                         RELIABILITY UP TO PHASE 1    IS [illegible]
RELIABILITY PHASE 1, 1, IS [illegible]   READINESS                    IS [illegible].2187
READINESS                IS 0.2187       AVERAGE AVAILABILITY         IS [illegible].821[illegible]
AVERAGE AVAILABILITY     IS 0.821[illegible]  INSTANT AVAILABILITY    IS [illegible].76[illegible]

A GRAND TOTAL OF   1[illegible] MISSIONS HAVE BEEN RUN.
THE RELIABILITY IS          [illegible]
THE LOWER CONF LIMIT IS   0.0
THE SPEC REQUIREMENT IS   1.0[illegible]
THE READINESS IS            0.2187
THE AVERAGE AVAILABILITY IS    0.8[illegible]
THE INSTANT AVAILABILITY IS    0.7[illegible]

THE MEAN TIME BETWEEN MISSION FAILURES IS        472.5
THE LCL,9[illegible], MTBMF IS                       -93.4
THE MTBMF VARIANCE VARIANCE IS                  1[illegible]431.5

THE SYSTEM MDT IS                   [illegible]15.3
THE SYSTEM MDT IS                  84.698
ANOTHER SET OF 5 MISSIONS WILL BE RUN TO OBTAIN REQUIRED
STATISTICAL CONFIDENCE.
```

TABLE XXI

Summary Tables

EQUIPMENT FAILURES AND CORRECTIVE MAINTENANCE SUMMARY

EQUIP NO.	TYPE NO.	TOTAL EQUIP. FAILURES	AVG NO FAILURES PER MISSION	AVG CM MANHOURS PER MISSION
1	1	782	2.607	312.800
2	2	583	1.943	97.167
		------	-------	---------
		1365	4.550	409.967

AVERAGE NUMBER OF SPARES USED PER MISSION

SPARES TYPE	SHIP STOCK	USED	TENDER STOCK	USED	BASE	USED
1	5	2.56	0	0.0	0	0.0
2	4	1.90	0	0.0	0	0.0

90 DAY .25 FLSIP EVALUATION OF MODEL SYSTEM

CRITICAL EQUIPMENTS

UNAVAILABILITY AND
PERCENT OF UNAVAILABILITY

NAME	NUM HRS	UNAVA	PERCENT	EQU TYPE	EQU NUM
ITEM A	86123.3125	0.1329	69.86	1	1
ITEM B	34262.5977	0.0529	27.79	2	2

90 DAY .25 FLSIP EVALUATION OF MODEL SYSTEM

CRITICAL EQUIPMENTS

UNRELIABILITY AND
PERCENT OF MISSION FAILURES

DESCRIPTION	NO. FAILURES	UNREL	PERCENT	EQUIP TYPE	EQUIP NO.
ITEM A	171.5	0.5716	57.74	1	1
ITEM B	125.5	0.4183	42.25	2	2

TOTAL NO. MISSIONS = 300
TOTAL NO. MISSION FAILURES = 297

LIST OF REFERENCES

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3. Jee, M. W., *Mathematical Models for Operational Availability*, PhD. Dissertation, U.S. Naval Postgraduate School, Monterey, 1980.

4. Naval Sea Systems Command Report TE660-AA-MMD-010, TIGER Manual, January, 1980.

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